Evaluation of the Advanced Locomotive Emissions Control System (ALECS)

ALECS Proof-of-Concept Testing at the Union Pacific J. R. Davis Rail Yard in Roseville, California

Report to
Placer County Air Pollution Control District
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Executive Summary

The Union Pacific Railroad's J.R. Davis Rail Yard in Roseville, California, is a major center for locomotive maintenance and repair, as well as for assembling and reassembling trains of freight cars. Over 90 percent of all Union Pacific rail traffic in Northern California goes through the yard. Locomotive operations at the rail yard have been determined to be a significant source of emissions of diesel particulate matter (PM) and other pollutants. An agreement between the Placer County Air Pollution Control District (PCAPCD) and the Union Pacific Railroad Company (UPRR) includes a mitigation plan for reducing PM emissions from the rail yard. Part of this plan is an assessment of the use of stationary air pollution control equipment to capture and treat emissions from motionless locomotives while idling or undergoing engine load tests during maintenance.

The Advanced Locomotive Emission Control System (ALECS) comprises a set of stationary emissions control equipment connected to an articulated bonnet. The bonnet is designed to capture locomotive exhaust, delivering it to the ground-based emission control system via ducting. The hood remains attached while the locomotive is moving slowly along the track to the extent of the ducting. The emission control equipment comprises a sodium hydroxide wash to remove sulfur dioxide (SO_2), a triple cloud chamber scrubber for PM removal, and a Selective Catalytic Reduction (SCR) reactor to reduce oxides of nitrogen (NO_x). The ALECS is designed to treat exhaust flows between 2,000 and 12,000 standard cubic feet per minute (scfm). The former is approximately the exhaust flow from a locomotive at idle, while the latter is approximately the exhaust flow from a line-haul locomotive at throttle notch 8 (full power).

The ALECS proof-of-concept was a public-private collaborative project involving the PCAPCD, U.S. Environmental Protection Agency (EPA), Sacramento Metropolitan Air Quality Management District (SMAQMD), UPRR, Advanced Cleanup Technologies Inc. (ACTI), the South Coast Air Quality Management District (SCAQMD), the California Air Resources Board (CARB), and the City of Roseville. Engine, Fuel, and Emissions Engineering, Inc. (EF&EE) was contracted by the SCAQMD to conduct emission measurements before and after the ALECS.

Emission measurements were performed on two locomotives: a General Motors Electro-Motive Division GP38 and a General Electric C39-8 (Dash 8). The GP38 has a 2000 horsepower two-stroke diesel engine, and is typically used for switching and local service. The Dash-8 has a 3900 horsepower four-stroke engine, and is normally used for line-haul freight service. Tests were performed with the locomotives motionless at notch 1, notch 3, notch 5, and notch 8 power settings, and while moving slowing back and forth along a small section of track.

Table 1 summarizes the overall average control efficiencies resulting from the proof-of-concept tests. Using these control efficiencies, estimates were made of the reduction in emissions that may result from use of one ALECS in a rail yard situation. The emission reductions are highly dependent on the specific operation addressed in a rail yard. Table 2 presents the range of emission reductions estimated for two very different applications in a rail yard. One case addresses all idling Tier 2 locomotives; while the other case utilizes Tier 0 locomotives addressing some load and diagnostic testing, with the remainder of the capacity servicing idling locomotives. These cases are meant to define the low and high end of possible emissions for the

ALECS. Actual rail yard installation will most likely yield emission reductions somewhere in between these two assumptions, depending on the specific application.

Table 1. Summary of Pollutant Control Efficiencies

	NO_x	HC	PM	SO_2
Overall Average Control Efficiency[1]	97.8%	62.7%	92.1%	97.3%

[1] ALECS demonstration at Roseville rail yard

Table 2. Range of Estimated Emission Reductions (tons/yr)

	NO_x	HC	PM
Mixed Loads Tier 0 Emissions	83.4	8.44	2.53
Idling Only Tier 2 Emissions	40.0	2.49	1.29

The fully loaded total initial capital cost of the ALECS (for an estimated 12 bonnet system) is $8,680,126 with an annual operational cost of $899,926. The 12 bonnet system is sized to cover an area of the rail yard that allows for at least six locomotives to be connected and running at all times.

Cost effectiveness of the ALECS has been estimated using the total life cycle costs based upon annualizing (and adjusting for the time value of money) the capital investment and the net present value (discounted cash flow) of future operation and maintenance costs for the range of pollutants removed by the two rail yard operating scenarios. The estimated cost effectiveness curve for the total weighted pollutants reduced over the 20 year life of ALECS is illustrated in Figure 1. Pollutants considered in this estimate are NO_x, HC, and PM. Oxides of sulfur (SO_x) emissions that are reduced were not included in this cost effectiveness calculation. The PM emissions were weighted by a factor of 20 as is the practice with the current Carl Moyer Incentive Program guidelines. This weighting was used in calculating cost effectiveness because of the toxicity level of PM. ALECS was estimated to be in full operation 96 percent of the time. The cost effectiveness ranged between $18,437/ton in the all idling mode to $7,297/ton of weighted pollutant reduced in the mixed mode of a combination of locomotives at idle and at loads during maintenance testing.

Noise measurements where made on some high power runs to assess possible noise reductions due to the bonnet attached over the locomotive exhaust stack. Measurements with, and without the bonnet attached yielded noise reductions of 5.3 to 6.8 decibels, representing noise energy reductions of 70 to 79 percent.

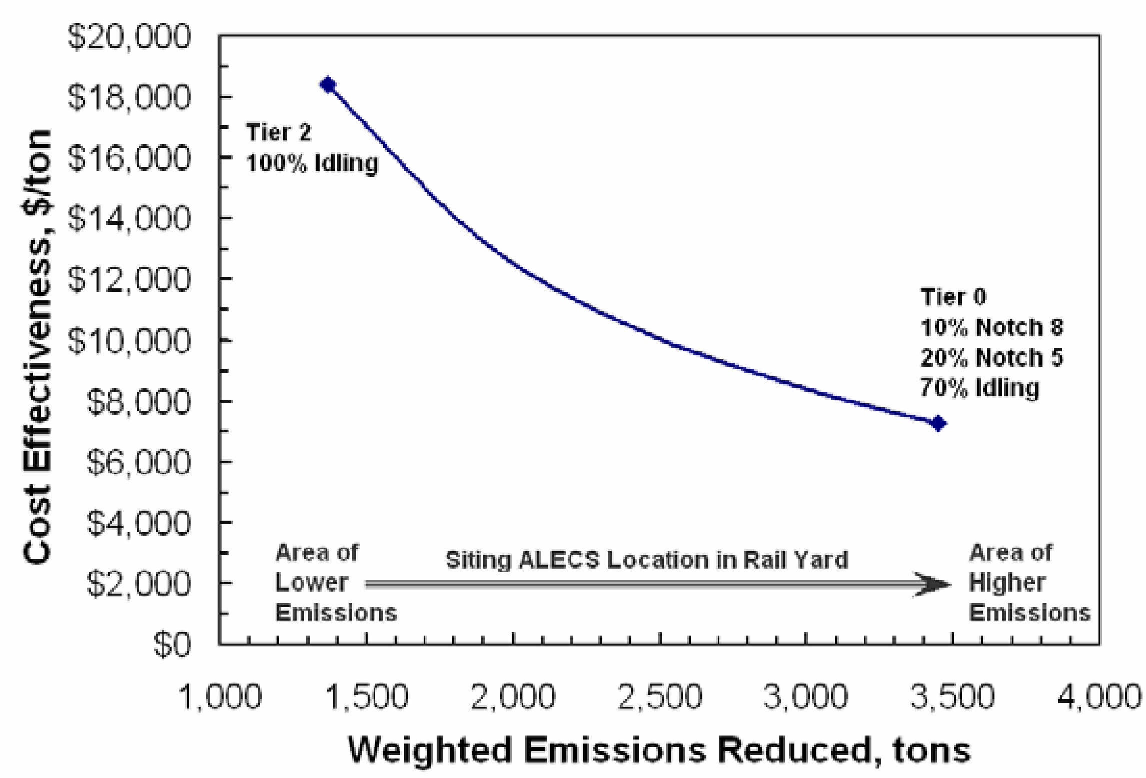

Figure 1. ALECS Cost Effectiveness

While the ALECS proof-of-concept tests met most of the project objectives and yielded valuable information confirming that the system is capable of capturing and treating locomotive emissions, there remains additional work in selected areas in order to support fielding a cost effective system in a rail yard application. The emissions capture subsystem, which includes the bonnet over the locomotive stack and the ducting that routes the exhaust to the emissions control subsystem, was designed to accommodate a single locomotive. The full-scale subsystem capable of capturing and transporting emissions from multiple locomotives was not tested. A number of follow-on actions are recommended, including public policy leadership, internal rail yard analyses with respect to optimal siting situations as well as positive and negative impacts to rail yard operations, demonstrating the emissions capture subsystem for multiple locomotives, developing financial mechanisms for the funding of systems, and community outreach.

1. Introduction

1.1 Project Background and Overview

Placer County Air Pollution Control District (PCAPCD) led a public-private collaborative project in a technology proof-of-concept test of a new concept to clean locomotive diesel exhaust. As a result of public concern over health risk from locomotive diesel emissions emanating from the J. R. Davis Rail Yard in Roseville, California, the PCAPCD arranged for the California Air Resources Board (CARB) to perform a detailed health risk analysis of locomotive diesel exhaust from the rail yard. Diesel exhaust was designated a toxic air contaminant by the CARB in 1998. This yard is one of the largest rail facilities in the western United States and serves as a maintenance and repair hub for locomotives. Over 90 percent of all Union Pacific rail traffic in Northern California moves through the yard (Union Pacific Railroad website, January 2007). The following lists some of the features of the rail yard (see Figure 2 for an aerial overview of the facility).

- Encompasses 915 acres
- 6 miles long
- 55 bowl tracks
- 136 miles of track
- 247 switches
- 2 main lines
- 6,500 rail car capacity
- 1,800-2,300 cars per day classification ability
- Over 30,000 locomotives stop annually
- Additional 15,000 locomotives pass through without stopping
- 21,500 locomotives receive service, maintenance, and/or repair per year
- 9,600 locomotives refueled only for fast turn-around per year
- Locomotives are fueled with 2.8 million gallons of diesel fuel per month

The effort was a public-private collaborative project involving the U.S. Environmental Protection Agency (EPA), California Air Resources Board, three Air Districts, one city government, and two corporations. The purpose of the project was to demonstrate the effectiveness of the stationary control equipment in capturing and treating locomotive exhaust, and to generate the information on capital and operating costs. The CARB Roseville Rail Yard Study (CARB, October 14, 2004) concluded “Computer modeling predicts potential cancer risks greater than 500 in a million (based on 70 years of exposure) northwest of the Service track area and the Hump and Trim area. The area impacted is between 10 to 40 acres.” These are the areas of the rail yard where servicing, fueling, and maintenance testing of locomotives occurs. Subsequent to the health risk findings, the PCAPCD negotiated an agreement with Union Pacific Railroad Company (UPRR) that included a number of measures to reduce diesel emissions. One measure was to investigate the use of stationary control equipment to clean up diesel exhaust captured from motionless or slow moving locomotives in service areas of the rail yard where numbers of locomotives are run for diagnostics and testing.

Figure 2. Aerial View of the J. R. Davis Rail Yard

In response to this measure, the PCAPCD organized and led a technology proof-of-concept test of an innovative new concept to capture locomotive diesel exhaust and remove the air pollutants using conventional stationary source techniques. This project is innovative in that conventional stationary source technology is applied to a mobile source through a novel bonnet type exhaust capture device (see Figure 3). Conventional emissions control equipment includes the Preconditioning Chamber, cloud chamber scrubbers and Selective Catalytic Reduction (SCR) to remove approximately 95 percent of oxides of nitrogen (NO_x), oxides of sulfur (SO_x), and particulate matter (PM). The novel bonnet device consists of a duct structure mounted above the locomotive track and a remotely guided bonnet that fits over the exhaust stack and can move with the locomotive to the extent of the overhead duct structure.

The cost of this collaborative project was covered by direct funding, a grant, in-kind contributions, and corporate product development. The contributing project participants were:

- U.S. Environmental Protection Agency (EPA)
- California Air Resources Board (CARB)
- Placer County Air Pollution Control District (PCAPCD)
- Sacramento Metropolitan Air Quality Management District (SMAQMD)
- South Coast Air Quality Management District (SCAQMD)
- City of Roseville
- Union Pacific Railroad Company (UPRR)
- Advanced Cleanup Technologies, Inc. (ACTI)

Figure 3. Locomotive under the Exhaust Capture Bonnet

1.2 Project Objectives/Motivations

The Advanced Locomotive Emission Control System (ALECS) proof-of-concept test project was a year and a half effort involving the development of locomotive-specific interfaces, temporary installation of emissions control equipment at the Roseville rail yard and testing motionless and slow-moving locomotives to determine the possible effectiveness of the control equipment.

The original objectives of the proof-of-concept test project are listed below (they will be compared to accomplishments later in this report):

> **Objective 1: Demonstrate the Possible Effectiveness of Stationary Control Equipment on Locomotive Exhaust:** This proof-of-concept test of the ALECS equipment should quantify the overall capture and control efficiency of particulate matter (PM), NO_x, SO_x, and total hydrocarbons (THC) with actual locomotive exhaust in a rail yard environment. Locomotive engines in common use come in two distinct technologies; two-stroke and four-stroke. This proof-of-concept test will test one engine of each technology; a GP38 two-stroke locomotive operating on ultra-low sulfur (15 ppmw) fuel, and a Dash-8 four-stroke locomotive operating on a fuel with a sulfur content between 200 ppmw and 500 ppmw. Sound measurements will be taken with and without the control equipment to determine the extent of noise reduction due to the control equipment (sound measurements added during the project).

Emissions testing will be conducted according to a test protocol developed for this project. The test protocol should prescribe accepted test methods appropriate to the pollutants being measured. The protocol will be reviewed by the air districts, CARB, and EPA. The testing will be conducted on the locomotive before the control equipment and upon exit from the control equipment to determine the emissions on a concentration and mass basis.

Objective 2: Demonstrate the Attachment Scheme between the Locomotive and the Stationary Control Equipment: Since a rail yard is a busy place where efficiency of operations is important, the attachment of the emissions control equipment to the locomotive must be quick, simple, and safe to the operating personnel. The operation of the ALECS must absolutely not impede the fluidity of normal railroad operations in any manner. Attachment, detachment, and capture efficiency will be demonstrated on locomotives with one and two emission stacks. During the emissions testing phase of this project, multiple attachments and disconnects shall be performed to demonstrate this capability. Rail yard personnel shall be given a chance to operate the attachment controls.

Objective 3: Demonstrate the Capability of Some Locomotive Movement While Connected to the Control Equipment: One of the design features of the ALECS is to allow movement of the locomotive along the track for a prescribed distance while connected to the emissions control equipment. During emissions testing, some portion of the testing on each locomotive shall be conducted with the locomotive connected to the stationary control equipment and the locomotive moving to demonstrate this capability while fully capturing the exhaust from the engine in the locomotive.

Objective 4: Develop Improved Information on Capital Cost, Operating Procedures, and Operating Costs: The underlying purpose of this proof-of-concept test project is to provide information on performance, operation and cost of using stationary emissions control equipment to treat locomotive exhaust in rail yards that will enable the railroad and equipment suppliers to make business decisions on moving forward in deploying this type of equipment. During the installation and operation of the ALECS, information shall be collected and recorded that will enable capital and life cycle costs to be generated. Rail yard facility requirements for infrastructure and support utilities will be defined. These cost estimates shall be documented in the final report. Railroad personnel shall be instructed on operation and maintenance of the ALECS during the proof-of-concept project, and will provide to the PCAPCD estimates for all costs for impacts to yard or system operations (either capital or operating) are included in the final accounting. These cost estimates will be included in the project final report.

The ALECS to be used for this proof-of-concept test is borrowed from another project where the equipment size was optimized for another application. As part of this objective, the cost of equipment appropriately sized and ALECS designed to serve the J. R. Davis Rail Yard will be estimated.

Objective 5: Document Test Results and Project Findings in a Final Report: Since this proof-of-concept test project has, as one purpose, the generation of information on performance and operation of the ALECS sufficient to allow railroads to make business decisions on use of this stationary control equipment on their rail yards, the project results will be documented in a final report. The final report will include, as a minimum, details of the locomotives tested, configuration of the test setup, test equipment, test conditions, and test methods, logistic and operation issues identified during project implementation, and emission (and noise) test results before and after the control equipment.

2. Description of Technology

2.1 Overall Description

ACTI's ALECS is designed to capture railroad locomotive exhaust emissions and direct them to an emissions treatment system for removal of harmful pollutants.

ALECS is comprised of two major subassemblies, the Emissions Capture Subsystem (ECS) and the Emissions Treatment Subsystem (ETS). The Emissions Capture Subsystem is the system used to capture the exhaust emissions from the locomotive and transport the captured exhaust to the Emissions Treatment Subsystem where a substantial amount of the harmful pollutants are removed.

2.2 Emissions Capture Subsystem

The Emissions Capture Subsystem (ECS) is designed to capture the exhaust emissions from locomotives while motionless or moving slowly within designated areas within a rail yard. The system is designed to capture the exhaust emissions from multiple locomotives. Locomotive exhaust is captured at the exhaust stack and directed through an Overhead Manifold to an emissions treatment system for removal of harmful pollutants.

The ECS is comprised of four major components: the Support Structure, Overhead Manifold, Emissions Intake Bonnet (EIB) and Control Software. The ECS is designed to provide the railroad with the maximum flexibility practical without interfering or impacting railroad operations.

System backpressure on the locomotive engine is controlled by a pressure sensor located within the bonnet, which in turn controls a damper located at the top of the bonnet. Backpressure is controlled between atmospheric and minus 0.25 inch of water gauge pressure, which puts the exhaust system under a slight vacuum. This vacuum essentially captures all of the locomotive's exhaust and may also add some dilution air from the surrounding atmosphere into the capture system.

2.2.1 Proof-of-Concept Test Configuration

For the proof-of-concept test, a scaled down version of the ECS was designed to show that exhaust emissions can be captured from various types of railroad locomotives with different exhaust flows and temperatures, stack configurations, and while immobile or moving within a designated area. Figure 4 shows the proof-of-concept test configuration. Capturing locomotive exhaust emissions was accomplished with the EIB located over the targeted locomotive and lowered around the locomotive exhaust stack (Figure 5 shows two bonnets lowered onto a locomotive).

The captured exhaust was then directed through an overhead manifold to the Emissions Treatment Subsystem. The proof-of-concept test overhead structure and intake manifold can be seen in Figure 6.

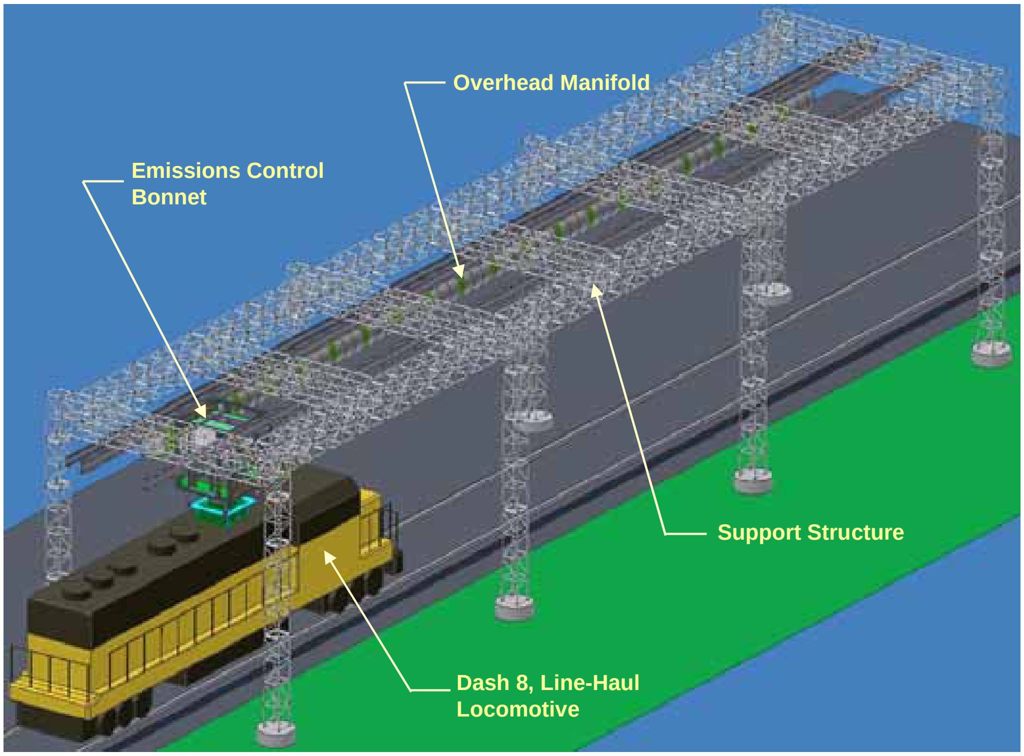

Figure 4. Proof-of-Concept Test Configuration of Emissions Capture Subsystem

Figure 5. Emissions Intake Bonnets Lowered onto a Locomotive

Figure 6. Overhead Structure and Intake Manifold

The short-term proof-of-concept test design of this project could only process the emissions from a single locomotive at a time. The full scale deployment design will need to cover multiple tracks and be able to receive emissions from multiple locomotives and direct the captured exhaust emissions to the Emissions Treatment Subsystem.

One of the functions of the ECS is to reduce or eliminate emissions of locomotives that may require maintenance. Figure 7 shows the visible smoke for a locomotive with high PM emissions. On occasion, visible exhaust emissions as shown in this figure have been observed from the stack of locomotives during engine startup, full power testing, and engine malfunction (invisible emissions can depend upon the atmospheric conditions, cold start of the engine, or throttle notch changes and may become less visible as equilibrium of the engine is attained).

2.2.2 Future Full Scale Deployment Concept

The future full scale deployment concept of the ECS was designed (for costing purposes) to be a versatile system that can be arranged to accommodate many rail yard configurations using common components. These components can be used to tailor a system to an area of the rail yard with varying numbers of parallel tracks of different lengths For the economic analysis, an ECS covering an estimated 1,200 feet of track was selected. The track can be three 400 foot sections side-by side, two 600 foot sections side-by-side or one continuous track at 1,200 feet in length, servicing 12 locomotives.

Figure 7. Visible Locomotive Exhaust Emissions

Shown in Figure 8 is an example of a future typical deployment of the ECS. Figure 9 depicts the system connected to the ETS, with arrows showing the path of the captured exhaust. Note that the system is designed to handle consist (multiple locomotives attached together to power a train) and standalone locomotives. However, the system that was tested in this project used only a single locomotive design.

The Support Structure is the metal framework that supports the Overhead Manifold and Emissions Intake Bonnets. It is comprised of steel Support Piers, Transverse Support and Longitudinal Support Beams.

The Overhead Manifold is the medium that directs the captured exhaust emissions to the ETS. It is comprised of an Intake Outer (Stainless Steel) Tube, an EIB Interface Inner-Connection (Stainless Steel) Tube, a Trolley Support Rail and Power Strip, and Control Cable Harness.

The EIB Interface Connection tube slides within the Intake Outer Tube to allow for automatic positioning of the bonnet over the selected locomotive exhaust stack.

The ECS will monitor exhaust flow rates from multiple locomotives and the exhaust from those locomotives producing the highest exhaust flow will be directed to the treatment system. This will selectively process the exhaust from the locomotives having the highest emissions (operating at the highest throttle notch), thereby optimizing the treatment systems effectiveness and efficiency in reducing the amount of harmful pollutants introduced into the surrounding atmosphere.

Figure 10 is a depiction of the Overhead Manifold, and shown in Figure 11 is a transparent view of the EIB Interface Connection Tube for the full scale, conceptual ECS design.

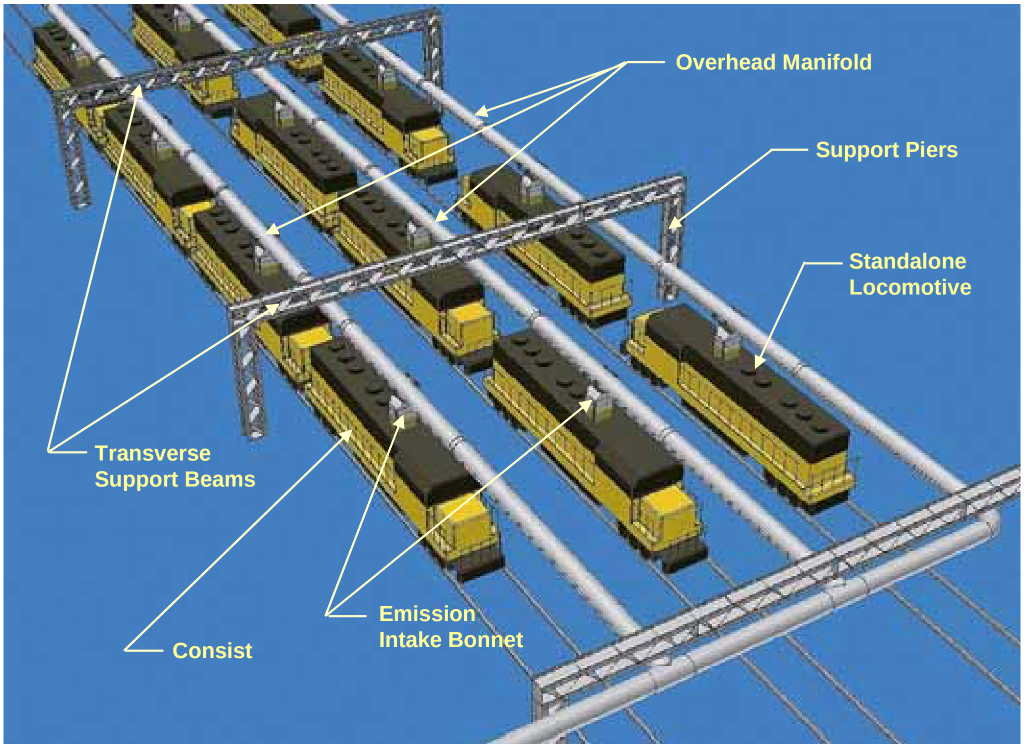

Figure 8. Conceptual Example Deployment of Emissions Capture Subsystem

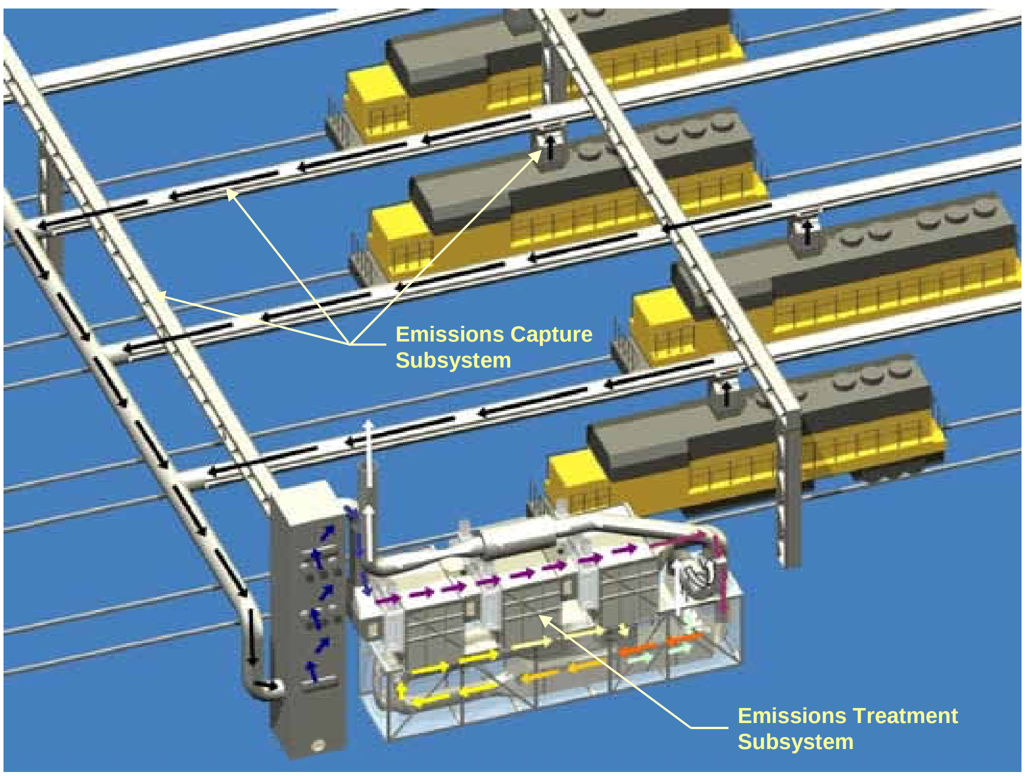

Figure 9. Conceptual Emissions Capture Subsystem Attached to the ETS

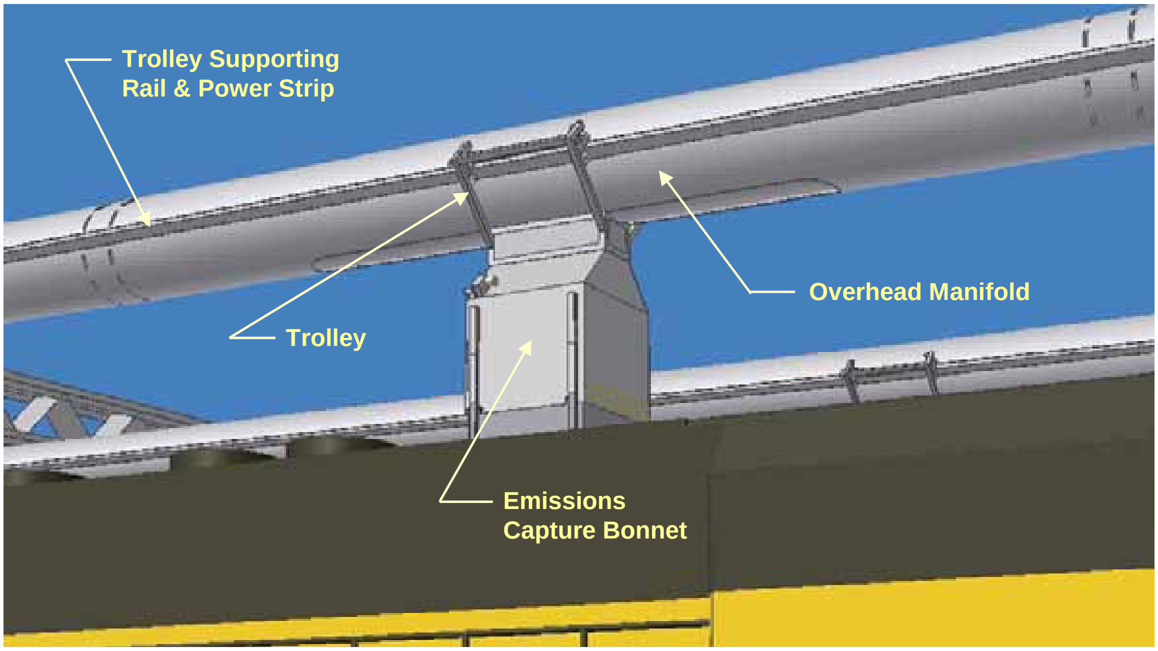

Figure 10. Conceptual Overhead Manifold and Emissions Control Bonnet

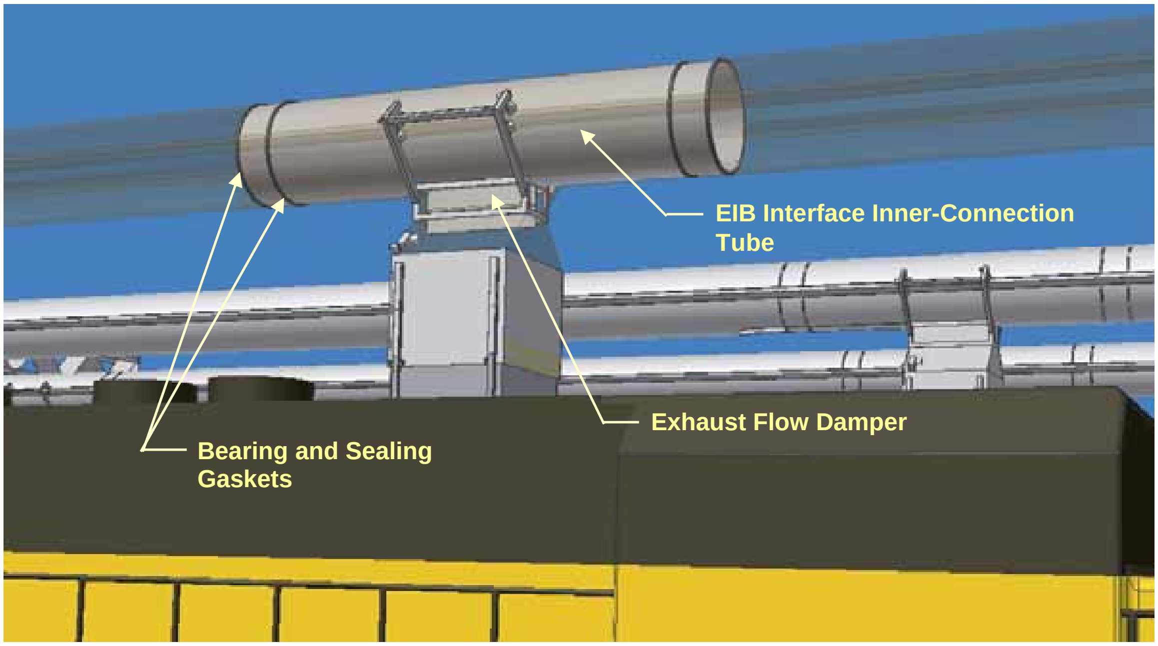

Figure 11. Conceptual Emissions Intake Bonnet and Interface Connection Tube

The EIB is the component that captures the exhaust emissions from locomotives by enclosing the exhaust stack and directing the exhaust emissions into the Overhead Manifold. The EIB is comprised of two components, the Intake Bonnet and the Trolley. The Trolley positions the Intake Bonnet over the locomotive's stack, and the stack lowering mechanism lowers the bonnet around the stack. For a conceptual depiction of the EIB Trolley see Figure 12.

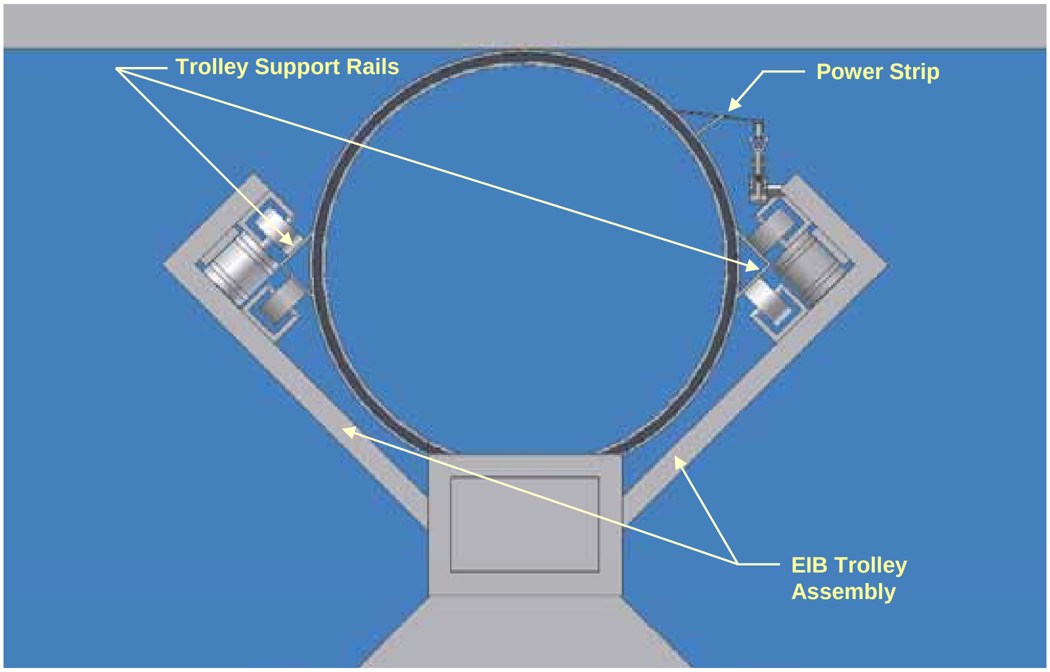

Figure 12. Conceptual Emissions Intake Bonnet Trolley

The ECS Control System will be programmed to automatically locate and connect to the locomotive stack. The system will detect when a locomotive enters the zone of operation. When the system determines that the locomotive has stopped, then a bonnet will be deployed. When the locomotive begins to move out of the zone, then the bonnet will automatically be retracted.

The ECS control system will also work to maximize the capture efficiency by prioritizing higher throttle notch levels over idling locomotives. As previously stated, each bonnet is connected through a control damper to the intake manifold. When a bonnet disconnects from a locomotive, the damper is completely closed to airflow. When a bonnet is connected to the locomotive, the damper is used to modulate the flow to keep the pressure within a negative ¼ inch of water pressure. When a higher exhaust flow rate of one or more of the locomotives is detected, the higher flow locomotive is prioritized over the lower notch and/or idling locomotives, which are temporarily disconnected from the system. The system also automatically connects as many locomotives as required to maintain the maximum flow rate of the ETS.

The bonnets are programmed to failsafe to the disengaged mode. Under any fault condition (e.g. loss of power, over/under pressure, over temperature) the system will disconnect from the locomotives and notify the technician on duty both locally in the Operational Control Unit (OCU) of the ETS and remotely by pager. In the event of an emergency or a failure, emergency stop pushbuttons can disconnect all bonnets, and bring the system to a safe operating condition.

2.3 Emissions Treatment Subsystem

The ETS consists of six major components: a Preconditioning Chamber (PCC) that removes SO_x and an amount of hydrocarbons (THC), a Cloud Chamber Scrubber (CCS) that removes PM, a Thermal Management System to increase operating efficiency, a Selective Catalytic Reduction

(SCR) Reactor for removal of NO_x, a Control System and the Continuous Emissions Measuring System (CEMS).

The ETS and the relative location of its components are shown in Figure 13 and are described further below. The Control system and CEMS descriptions follow these ETS major component descriptions.

The first component the exhaust gas encounters as it enters the system is the Preconditioning Chamber (PCC) which serves several functions. First, it cools the gas adiabatically through a counterflow water spray and in the process increases the water vapor content to near saturation. This feature is required by the following stage, which cannot accept hot gas. Secondly, it removes most of the soluble hydrocarbons and other water soluble compounds. Third, the water is rendered caustic by means of a metered injection of sodium hydroxide to remove 95 to 99 percent of the SO_2, depending on the inlet concentration. The fourth function of the PCC is to cause the nanometer size PM particles to agglomerate into larger particulate globules, which facilitates their removal in the next stage

The path of the exhaust emissions flow through the ETS, along with the relative positions of the major components is shown in Figure 14.

The gas exits the PCC at a temperature of about 140°F. This gas is directed to the first of three Cloud Chamber Scrubbers (CCS). These vessels are empty, except that they are filled with a fog of minute water droplets generated by an array of spray nozzles collinear with the exhaust gas stream. Each droplet is charged to a high voltage immediately after leaving its nozzle. This charge causes particulate matter in the gas stream to be attracted to and adhere to the water droplets, with each of the billions of water droplets collecting many particles. The droplets fall to the bottom of the CCS to a collection reservoir. Droplets entrained in the gas stream are removed by a mist eliminator.

The particles thus collected in the water reservoir are flushed through a solids removal system where they are collected for subsequent removal from the premises and disposal using approved regulatory means. The removal system consists of a solids separation device for inline solids removal, water extraction, and compaction.

The Selective Catalytic Reduction (SCR) Reactor requires a temperature of approximately 600°F to operate. The exhaust gas exiting the CCS is cooled to about 140°F and stripped of SO_2, PM, soluble hydrocarbons, and condensed (particulate) hydrocarbons and sulfates. This clean but cool gas must then be reheated. This is accomplished by a Thermal Management System (Burner & Heat-Exchanger) that is connected to the system in a wraparound arrangement. In this scheme, the hot exhaust from the SCR Reactor is used to heat the cold gas entering the SCR Reactor. Approximately 80 percent of the available heat is recovered from the hot gas leaving the SCR Reactor by this heat exchanger. The additional heat increment required to bring the gas stream up to 600°F is provided by a natural gas or propane-fired burner.

The exhaust emissions flow through the Thermal Management System with the relative positions of the components shown below in Figure 15.

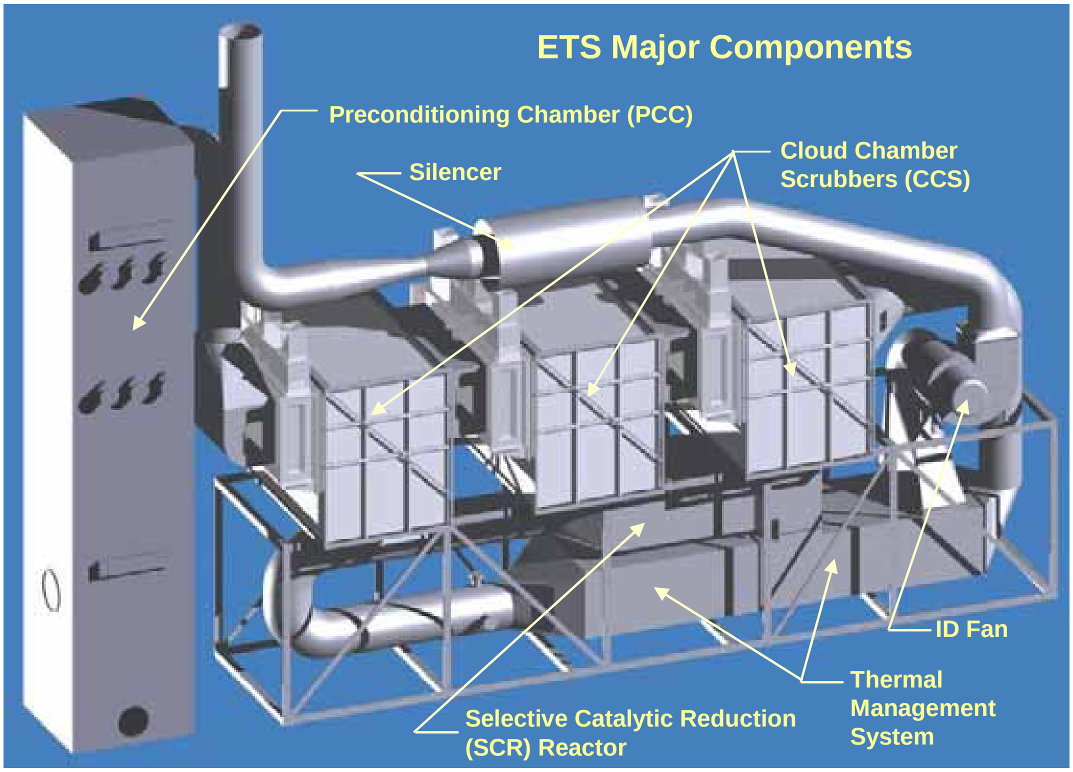

Figure 13. ETS with Relative Locations of Its Components

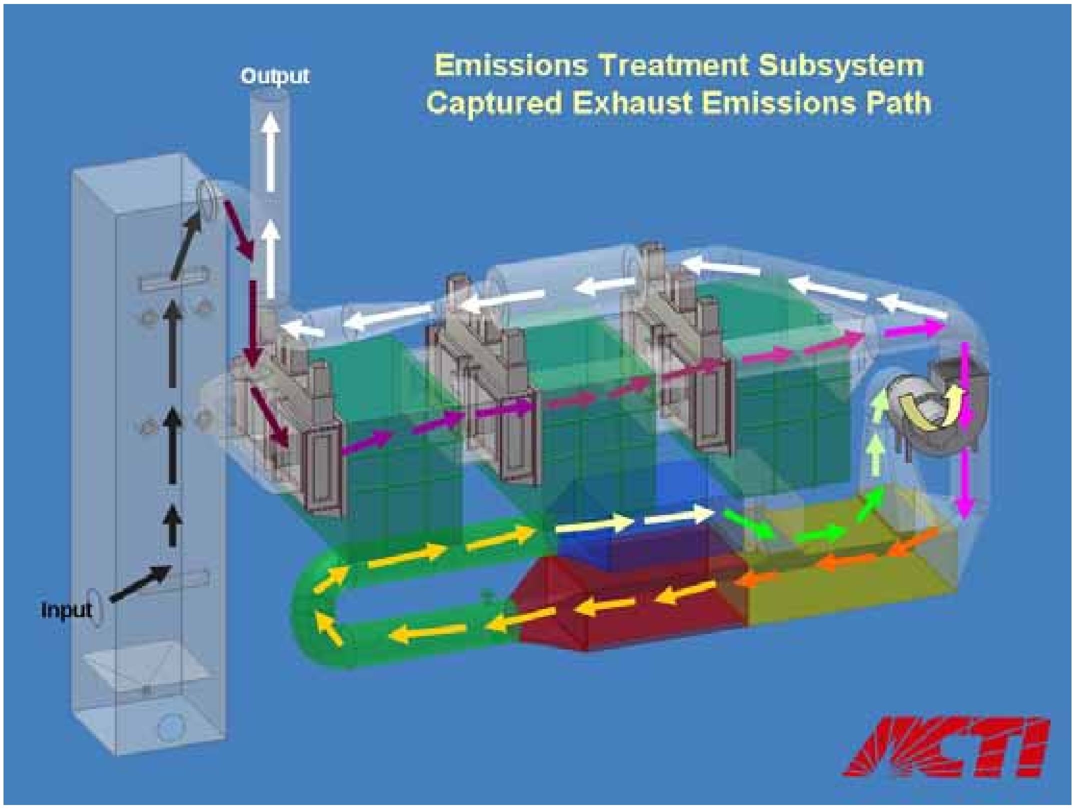

Figure 14. Emissions Treatment Subsystem Captured Exhaust Emissions Path

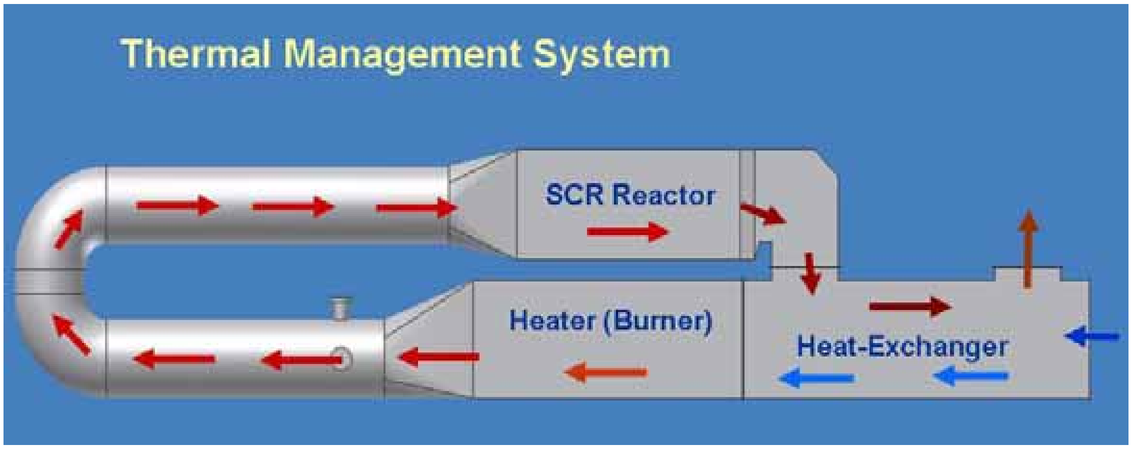

Figure 15. ETS Thermal Management System

The reheated gas at 600°F is passed through the SCR Reactor for NO_x removal. In the SCR Reactor, ammonia combines chemically with NO in the presence of the catalyst, converting the NO and ammonia (NH_3) into water vapor and nitrogen gas. Urea is the reagent this system uses as the source of ammonia. The urea is injected into the system immediately after the burner. Special atomizer nozzles and flow modification devices ensure uniform distribution, and a long mixing duct assures complete conversion of urea to ammonia.

An Induced Draft (ID) fan is located downstream of the SCR Reactor and Thermal Management System, and a silencer is located downstream of the ID fan. This fan draws the exhaust gas from the locomotive through the ducting into the ETS. The flow and pressures are controlled by dampers and the fan's variable speed drive motor.

In addition to the silencer, which acts as a muffler, the downstream ducting and fan housing are acoustically insulated to ensure that the systems operating noise level is reduced to an acceptable level.

Figure 16 shows the ETS in Roseville, California (it was not connected to the ECS yet).

Control System Description

The ALECS Control System is an integrated network which automatically operates and monitors all aspects of the ALECS operation. The ETS has its own Operational Control Unit (OCU), which controls all the ETS processes including any attached ECS. The ETS can be monitored and controlled locally (in the OCU) and remotely. The OCU houses all sensing, monitoring, recording and control system functions for ALECS. These systems acquire, monitor, store and transmit the data required to maintain efficient emissions control operations as well as to document emissions reduction performance during acceptance testing and certification. The OCU operates automatically, adjusting for the wide range of variables in the number of locomotives and their operating characteristics, compensating for changes in real-time.

Figure 16. Emissions Treatment Subsystem in Roseville Rail Yard

Failsafe strategies are built into the control system. This system keeps all ECS and ETS operational parameters within design limits, makes automatic adjustments where appropriate, switches to redundant components or systems in the event of a malfunction or out-of-spec condition, and records significant parameters to verify performance.

As part of the control system, measured data will be recorded in a Microsoft SQL relational database by locomotive identification number.

Continuous Emissions Monitoring System (CEMS)

The CEMS measures the following parameters:

- At the ETS inlet (source measurement)
  - NO_x
  - SO_x
  - O_2
  - PM (time shared with the outlet)
  - Flow
  - Temperature

- At the ETS outlet (discharge to atmosphere)
  - NO_x
  - SO_x
  - O_2
  - THC
  - NH_3 (ammonia)
  - PM (time shared with the inlet)

- Flow
- Temperature

PM is measured at the inlet and outlet using a Dekati Mass Measuring system with a single instrument. This arrangement uses a three-way valve to allow time sharing between the inlet and the outlet by switching the instrument input between sample lines.

Instrumentation Description

The gaseous instrumentation is a Horiba Instruments model ENDA-4000 stack gas analysis system. It uses chemiluminescent analysis for NO_x, non-dispersive infrared (NDIR) for SO_x, and magnetopneumatic analysis for the oxygen (O_2) measurements. A Horiba FIA-236 flame ionization analyzer is used to measure total hydrocarbons. NH_3 is measured by converting the NH_3 to NO in dual stream heated probes with an electrically heated filter chamber in the probe heated to 320°C. NH_3 is determined by measuring the NO thus produced and comparing it to the level without the NH_3 contribution to NO. The NH_3 system includes a built-in Horiba CLA-510 chemiluminescent NO_x analyzer for the NH_3 measurement.

The sample conditioning system includes a solid state thermoelectric pre-cooler with stainless steel impingers, a solid state thermoelectric sample cooler, primary and secondary particulate filters, an acid mist catcher, magnetically coupled sample pump and booster pump, temperature controller for the heated sample line, temperature controller for the sample probe primary filter, automatic temperature and pressure control, and automatic system calibration.

The sampling system consists of a stainless steel sample probe with heated primary filter and automatic blowback, and a heat traced multiple tube sample umbilical. The probe assembly consists of a probe pipe, heated primary filter and NEMA 4X enclosure. Connections route calibration gas upstream of the primary filter. The sampling system on the downstream side of the ETS adds dual stream heated probe heads with integral NH_3 converters and a 2 micron ceramic filter element heated to 320°C.

The sample system is shown in simplified form in Figure 17. Figure 18 is a picture of the CEMS utilized in the proof-of-concept testing.

PM is measured with the Dekati DMM-230 Mass Monitor manufactured by Dekati, Ltd. in Finland. This instrument gives one second data points of particle size as well as other particle statistics. The DMM operation principle is based on measuring particle electrical mobility and aerodynamic size. These two parameters are compared in real time to determine total mass.

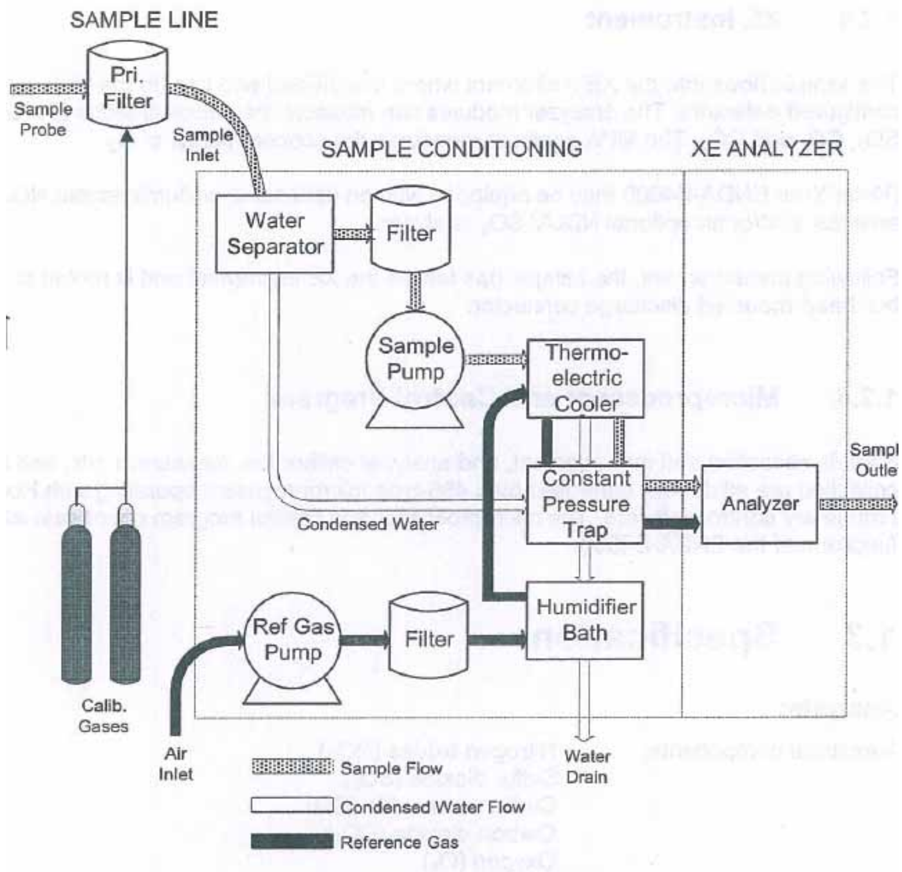

Figure 17. Simplified Diagram of the CEMS Sample System

Figure 18. ALECS CEMS

2.4 Site Preparation and System Installation for Proof-of-Concept Tests at Roseville

Prior to the system being shipped to Roseville, a site was selected that would not interfere with railroad operations and that was safe for operational personnel and visitors. Figure 19 shows an aerial view of the approximate location of the ALECS proof-of-concept test site in the Roseville rail yard. The site was readied by pouring a concrete pad, and as the location did not have easy access to electrical power lines or natural gas, a temporary diesel generator using a Tier 2 engine and a propane engine driven generator were bought in to supply electricity and temporary propane tanks were installed to provide fuel for the burner and propane generator.

Figure 19. Aerial View of the Site Where the ALECS was Installed

The entire system was shipped to the site on flatbed trucks from the various fabrication locations where the components were manufactured and tested. The system was then assembled, tested and readied for demonstration and testing.

With the exception of visitors, all non-railroad personnel underwent rail yard safety training.

3. Testing of System

3.1 Overall Test Plan/Matrix

The test program consisted of testing two locomotives made available by the Union Pacific Railroad that are representative of common high-use locomotives at the Roseville rail yard; one a line-haul locomotive and the other a switcher locomotive. These two locomotives were carefully selected to provide a range of design parameters seen in the locomotive technologies prevalent at Roseville.

Development of the proof-of-concept test plan was a collaborative effort by members of the project team and the emissions testing contractor. Organizations active in this plan development were PCAPCD, ACTI, EPA, CARB, SCAQMD, UPRR's consultant Sierra Research, TIAX, and EF&EE. The goal of the plan development was to demonstrate the ALECS performance over a range of locomotive variations with limited funding available for the testing. A challenge was to come up with test methods suitable for a system that contained a stationary source and a mobile source. Table 3 summarizes the conditions and the number of tests listed in the test plan for the two locomotives to be used with the ALECS.

The resulting test protocol defined the exhaust parameters to be measured and recorded, the sampling locations, the test methods, and the locomotive configurations and throttle settings to be tested. The complete test protocol is included as Appendix A.

Table 3. Summary of Planned Tests

Locomotive	Throttle Notch	Number of Tests per Location	Location of Tests		
			Locomotive Stack	ALECS Inlet	ALECS Outlet
Dash-8	8	3	X	X	X
	5	3	X	X	X
	1	3	X	X	X
	3 (soup baseline)	3	X	X	X
	3 (souping test)	3	X	X	X
	Moving	3	X	X	X
GP38	8	3	X	X	X
	5	3	X	X	X
	1	3	X	X	X
	3 (soup baseline)	3	X	X	X
	3 (souping test)	3	X	X	X
	Moving	3	X	X	X

Each locomotive was tested in a motionless condition and also moving slowly over a 50-foot section of track. The immobile locomotive testing was conducted at four throttle settings; notch 1, notch 3, notch 5 and notch 8. The moving test was conducted at low throttle settings to continuously move the locomotive back and forth along 50 feet of track while connected to the overhead ducting. Three tests were conducted for each individual condition.

The test program included emission measurements at three locations; in the locomotive stack(s), in the inlet ducting to the ground-mounted emission treatment system (Figure 20 shows the ducting between the emissions capture system and the emissions treatment system where measurements were taken), and at the outlet from the emission treatment system (Figure 21 shows the exhaust stack outlet measurement location as well as the inlet measurement location).

Pollutants measured included PM, NO_x, CO, SO_2, and THC. Test procedures for these pollutants conformed to ISO standard 8178. Ammonia (NH_3) was measured only at the inlet and outlet of the emission control system, following EPA Method 320.

Noise measurements were made for each locomotive at notch 8, both with and without the bonnet attached to the exhaust stack. These tests were conducted to evaluate the level of noise reduction that can be attributed to use of the ALECS.

Figure 20. Ducting between the ECS and the ETS

Figure 21. Exhaust Stack of the Emissions Treatment Subsystem

3.2 Locomotives Tested (GP38 and Dash-8)

The larger of the two locomotives tested was a General Electric (GE) C39-8 locomotive (representative of the Dash-8 series) used primarily for line-haul freight service and was equipped with a four-stroke, turbocharged, GE FDL-16 engine. This 16 cylinder engine produces 3,900 tractive horsepower, and discharges exhaust through a single rectangular stack connected directly to the turbocharger outlet. The maximum exhaust flow rate at full power is approximately 12,000 scfm. The test locomotive was identified with the serial number 9143 (see Figure 22).

The smaller locomotive tested was a General Electric Electro-Motive Division (EMD) GP38 (Figure 23). At Roseville, this type of locomotive is used primarily for switching and local service. It was equipped with a two-stroke, Roots-blown, EMD 16-645E engine. The engine has 16 cylinders and is rated at 2,000 tractive horsepower. It is equipped with two exhaust stacks, fed by the front eight and rear eight cylinders, respectively. The maximum exhaust flow rate at full power is approximately 6,000 scfm. The test locomotive was identified with the serial number 604. Table 4 summarizes the locomotive characteristics.

Immobile locomotive tests consisted of triplicate tests of each locomotive running at throttle notch 1, notch 5, notch 8, souping baseline at notch 3, and the souping test at notch 3. "Souping" is the term used for material buildup (such as oils and PM) in the exhaust system at light loads which burns off at higher loads. The souping baseline test is a test run at a throttle setting that is high enough where souping does not occur (notch 3) in order to evaluate steady state emissions. The souping test is run immediately after the notch 1 test to measure the soup that accumulated during the notch 1 test and is burned off in a higher notch run, and then compared to the souping baseline emissions rate.

Figure 22. Single Stack Line-haul Dash-8 Locomotive

Figure 23. Double Stack Switcher GP38 Locomotive

Table 4. Locomotive Characteristics

	Locomotive	
	Dash-8	**GP38**
Locomotive Service Class	Line-haul	Switcher
Locomotive Model	GE C39-8	EMD GP38
Locomotive Identification Number	9143	604
Engine Model	GE FDL-16	EMD 16-645E
Engine Type	Four-stroke	Two-stroke
Number of Cylinders	16	16
Rated Power Output (horsepower)	3,900	2,000
Number of Exhaust Stacks	1	2
Maximum Exhaust Flow Rate	12,000 scfm	6,000 scfm

Locomotive noise measurements were performed using a hand-held noise meter. Measurements were made at a point 30 meters away from the locomotive along a line passing through the center of the locomotive perpendicular to the track. Noise measurements were taken at the throttle notch 8 operating condition with the bonnet attached and unattached. Noise measurements on a moving locomotive were deemed not necessary due to the low throttle notch settings.

The triplicate moving tests were conducted with the bonnet(s) attached to the locomotive stack(s) and each locomotive moved back and forth under its own power within the 50 feet of test section. The moving tests were conducted for 30 minutes of continuous back and forth motion in which the locomotive throttle was set at notch 1 and the drive was engaged to move and then disengaged from the drive using the brakes to stop.

Additional information on the test conditions can be found in Appendix A and B which contains the test plan and emission test report respectively.

3.3 Emission Measurements

The emissions testing contractor, Engine, Fuel, and Emissions Engineering (EF&EE), used their patented Ride-Along Vehicle Emissions Measurement (RAVEM) sampling system to perform the PM emissions measurements. The RAVEM uses the isokinetic partial flow dilution method specified as one option under ISO 8178. Separate RAVEM samplers were used to sample the exhaust at the locomotive stack, at the inlet to the ALECS (see Figure 24), and in the outlet stack from the ALECS.

The RAVEM system located at the ALECS inlet was configured to measure NO_x, CO, and CO_2 continuously, as well as collecting integrated bag samples of the dilute gas to be analyzed after the end of each test. The RAVEM samplers at the outlet and at the locomotive stack collected integrated bag samples only. These were analyzed at the end of each test by the analyzers of the first RAVEM system.

Figure 24. RAVEM Setup at the Inlet to the Emissions Treatment Subsystem

The ALECS system itself includes continuous emission monitoring systems (CEMS) for NO_x, SO_2, and O_2 at both the inlet and the outlet, and for THC and NH_3 at the outlet only. For these tests, EF&EE provided another THC analyzer for the inlet. Table 5 shows the equipment (EF&EE or ALECS CEM) used to measure emissions by sampling location.

Table 5. Source of Measurements by Sampling Location

	Locomotive Stack	ALECS Inlet	ALECS Outlet
NO_x	E	A, E	A, E
THC	—	E	A
CO	E	E	E
CO_2	E	E	E
SO_2	—	A	A
NH_3	—	E	A, E
N_2O	—	E	E
PM	E	E	E

A = ALECS CEM system equipment
E = EF&EE system equipment

4. Test Results

All of the data taken at the ETS inlet and outlet locations by EF&EE with their RAVEM are presented here (PM, NO_x, CO, and CO_2). NO_x data taken by the ALECS' CEMS will not be presented here because only the NO_x data taken by EF&EE will be used. Although the NO_x data from ALECS's CEMS were not used, there was a good correlation with the RAVEM NO_x data (see the emission test report in Appendix B for comparisons of the two sets of data). However, the SO_2, THC, and NH_3 data taken by the ALECS' CEMS will be presented (EF&EE did not perform these measurements).

The original intent of sampling and analyzing the exhaust at the locomotive stack location was to see if the ducting to the inlet of the ALECS changed any of the results. Unfortunately, the measures at the locomotive stack were influenced by non uniform flow which introduced uncertainties that rendered these data unusable. Also, the nitrous oxide (N_2O) data were too low to be reported by EF&EE. Therefore the data for the locomotive stack location and N_2O data will not be addressed in this report (see the emission test report in Appendix B for a more thorough explanation of the details).

4.1 Emissions Results

Table 6, Table 7, and Table 8 presents the inlet and outlet emission results to the Emission Treatment System (ETS) measurements performed by EF&EE's RAVEM system for the motionless Dash-8, motionless GP38, and moving locomotives respectively.

Table 9, Table 10, and Table 11 are the inlet and outlet emissions results from ALECS' CEMS for the pollutants not measured by EF&EE. They are for the immobile Dash-8, immobile GP38, and moving locomotive tests respectively. The ammonia slip from the use of urea in the SCR system was very low. The average ammonia slip ranged from 0 up to 1.3 g/min (around 3 ppm for an exhaust flow rate of 12,000 scfm).

The CO_2 and CO results show that there are more of these pollutants coming out of the system than what entered (this is reflected in the negative control efficiency values). The increase in CO and CO_2 are attributed to the propane fuel burned to reheat the exhaust gas before the SCR system.

The overall emission control efficiency of the major pollutants of interest is presented in Table 12.

Table 6. ALECS Inlet/Outlet Emissions — RAVEM Data for the Motionless Dash-8

	Inlet Emissions				Outlet Emissions[1]			
	CO_2	CO	NO_x	PM	CO_2	CO	NO_x	PM
Notch 8 Average (g/min)	30,207	119	648	25.5	33,808	146	20.4	2.9
Coefficient Of Deviation	2.5%	6.5%	3.9%	7.9%	5.0%	8.0%	25.9%	6.2%
Control Efficiency					**-11.9%**	**-22.0%**	**96.8%**	**88.8%**
Notch 5 Average (g/min)	18,111	128	427	6.4	21,073	151	6.7	1.2
Coefficient Of Deviation	3.7%	10.8%	2.7%	8.9%	8.2%	18.0%	71.9%	12.9%
Control Efficiency					**-16.4%**	**-18.1%**	**98.4%**	**80.9%**
Notch 1 Average (g/min)	3,785	17	97	4.6	3,623	18	1.9	0.1
Coefficient Of Deviation	6.0%	45.6%	8.4%	6.5%	3.8%	6.0%	107%	2.9%
Control Efficiency					**4.3%**	**-3.0%**	**98.1%**	**98.6%**
Souping Baseline Ave. (g/min)	11,020	37	267	3.8	12,069	48	0.0	0.4
Coefficient Of Deviation	1.6%	11.6%	1.6%	18%	12.0%	29.5%	141%	22.0%
Control Efficiency					**-9.5%**	**-28.5%**	**100%**	**90.7%**
Souping Test Average (g/min)	10,841	41	257	18.2	12,509	58	7.7	0.5
Coefficient Of Deviation	8.0%	19.8%	5.3%	64%	7.0%	8.7%	101%	65.4%
Control Efficiency					**-15.4%**	**-42.6%**	**97.0%**	**97.0%**

[1] Negative control efficiencies are due to the increase of CO_2 and CO from burning propane fuel to reheat the exhaust before entering the SCR.

Table 7. ALECS Inlet/Outlet Emissions — RAVEM Data for the Motionless GP38

	Inlet Emissions				Outlet Emissions[1]			
	CO_2	CO	NO_x	PM	CO_2	CO	NO_x	PM
Notch 8 Average (g/min)	19,411	37	466	6.6	21,466	45	6.8	0.6
Coefficient Of Deviation	6.0%	18.2%	0.8%	16%	3.5%	6.5%	129%	27.8%
Control Efficiency					**-10.6%**	**-24.0%**	**98.6%**	**90.7%**
Notch 5 Average (g/min)	9,869	3	205	4.7	11,150	14	1.4	0.4
Coefficient Of Deviation	1.5%	77.3%	2.0%	16%	2.6%	32.3%	101%	6.2%
Control Efficiency					**-13.0%**	**-324%**	**99.3%**	**90.7%**
Notch 1 Average (g/min)	1,518	(1)	27	0.32	2,257	4	0.8	0.03
Coefficient Of Deviation	11.0%	638%	2.6%	34%	1.5%	31.7%	194%	9.4%
Control Efficiency					**-48.7%**	**#N/A**	**97.0%**	**89.6%**
Souping Baseline Ave. (g/min)	5,630	1	106	1.7	6,347	8	1.6	0.2
Coefficient Of Deviation	7.2%	159%	7.1%	14%	6.4%	18.9%	79.8%	6.4%
Control Efficiency					**-12.7%**	**-474%**	**98.4%**	**90.8%**
Souping Test Average (g/min)	5,327	(2)	99	2.9	5,817	8	4.8	0.1
Coefficient Of Deviation	15.0%	55.5%	8.4%	17%	11.5%	13.7%	133%	14.0%
Control Efficiency					**-9.2%**	**#N/A**	**95.2%**	**94.9%**

[1] Negative control efficiencies are due to the increase of CO_2 and CO from burning fuel to reheat the exhaust before entering the SCR.

Table 8. ALECS Inlet/Outlet Emissions — RAVEM Data for the Moving Tests

	Inlet Emissions				Outlet Emissions[1]			
	CO_2	CO	NO_x	PM	CO_2	CO	NO_x	PM
Dash-8 Moving Test Average (g/min)	1,797	6	43	3.2	2,303	12	0.6	0.0
Coefficient Of Deviation	40.3%	97.6%	35.4%	71%	13.9%	38.9%	129%	16.8%
Control Efficiency					**-28.2%**	**-99.4%**	**98.7%**	**98.5%**
GP38 Moving Test Average (g/min)	898	2	22	0.2	1,661	3	0.8	0.0
Coefficient Of Deviation	18.6%	70.9%	6.5%	116%	8.2%	20.1%	158%	66.8%
Control Efficiency					**-84.9%**	**-47.7%**	**96.3%**	**93.5%**

[1] Negative control efficiencies are due to the increase of CO_2 and CO from burning fuel to reheat the exhaust before entering the SCR.

Table 9. ALECS Inlet/Outlet Emissions — CEMS data for the Motionless Dash-8

	Inlet		Outlet		
	SO_2	THC	SO_2	THC	NH_3
Notch 8 Average (g/min)	27.34	9.90	0.07	6.64	1.3
Coefficient Of Deviation	10.4%	24.0%	198.7%	8.7%	17.8%
Control Efficiency			**99.7%**	**32.9%**	
Notch 5 Average (g/min)	18.16	4.06	0.00	2.79	0.8
Coefficient Of Deviation	8.3%	1.3%	173.2%	37.7%	103.9%
Control Efficiency			**100%**	**31.4%**	
Notch 1 Average (g/min)	1.44	1.39	0.01	0.59	0.3
Coefficient Of Deviation	4.3%	31.5%	97.4%	33.4%	136.0%
Control Efficiency			**99.1%**	**57.6%**	
Souping Baseline Ave. (g/min)	10.87	3.90	0.00	2.60	0.0
Coefficient Of Deviation	14.4%	2.1%	0.0%	13.5%	115.2%
Control Efficiency			**100.0%**	**33.2%**	
Souping Test Average (g/min)	9.42	4.61	0.07	2.24	0.1
Coefficient Of Deviation	6.6%	8.7%	104.9%	37.0%	75.5%
Control Efficiency			**99.2%**	**51.4%**	

Table 10. ALECS Inlet/Outlet Emissions — CEMS Data for the Motionless GP38

	Inlet		Outlet		
	SO_2	THC	SO_2	THC	NH_3
Notch 8 Average (g/min)	16.23	3.38	0.00	0.90	0.1
Coefficient Of Deviation	0.2%	9.3%	0.00	1.7%	173.1%
Control Efficiency			**100.0%**	**73.2%**	
Notch 5 Average (g/min)	4.70	1.62	0.00	0.23	0.0
Coefficient Of Deviation	1.4%	7.8%	0.00	2.4%	99.0%
Control Efficiency			**100.0%**	**85.7%**	
Notch 1 Average (g/min)	0.17	0.52	0.02	0.09	0.6
Coefficient Of Deviation	52.4%	13.9%	173.2%	11.2%	169.1%
Control Efficiency			**88.4%**	**83.1%**	
Souping Baseline Ave. (g/min)	1.35	0.95	0.00	0.14	0.0
Coefficient Of Deviation	20.9%	9.7%	0.00	10.6%	157.3%
Control Efficiency			**100.0%**	**84.9%**	
Souping Test Average (g/min)	1.14	0.97	0.05	0.15	0.2
Coefficient Of Deviation	22.2%	5.3%	173.2%	7.4%	87.6%
Control Efficiency			**96.0%**	**84.2%**	

Table 11. ALECS Inlet/Outlet Emissions — CEMS Data for the Moving Tests

	Inlet		Outlet		
	SO_2	THC	SO_2	THC	NH_3
Dash-8 Moving Test Average (g/min)	0.75	1.27	0.00	0.56	0.000
Coefficient Of Deviation	36.6%	35.3%	0.0%	60.9%	100.2%
Control Efficiency			**100.0%**	**56.0%**	
GP38 Moving Test Average (g/min)	0.24	0.46	0.04	0.10	0.000
Coefficient Of Deviation	9.1%	1.1%	173.2%	9.6%	139.2%
Control Efficiency			**84.9%**	**78.6%**	

Table 12. Average Control Efficiencies of the Major Pollutants

Locomotive	Throttle Notch	NO_x	THC	PM	SO_2
Dash-8	8	96.8%	32.9%	88.8%	99.7%
	5	98.4%	31.4%	80.9%[1]	100.0%
	1	98.1%	57.6%	98.6%	99.1%
	3 (soup baseline)	100.0%	33.2%	90.7%	100.0%
	3 (souping test)	97.0%	51.4%	97.0%	99.2%
	Moving	98.7%	56.0%	98.5%	100.0%
GP38	8	98.6%	73.2%	90.7%	100.0%
	5	99.3%	85.7%	90.7%	100.0%
	1	97.0%	83.1%	89.6%	88.4%
	3 (soup baseline)	98.4%	84.9%	90.8%	100.0%
	3 (souping test)	95.2%	84.2%	94.9%	96.0%
	Moving	96.3%	78.6%	93.5%	84.9%
Overall Average Control Efficiency		**97.8%**	**62.7%**	**92.1%**	**97.3%**

[1] The anomalous low average PM value (in comparison to the other PM control efficiencies) has been investigated by ACTI, but it could not be explained. The data is included in the overall average calculation for completeness.

4.2 Utility, Energy, and Chemical Consumption Rates

ACTI collected operating process data on the ALECS and provided the estimates shown in Table 13 on the utility, energy, and chemical consumption rates per hour of operation. Propane was the fuel used for reheating the exhaust prior to the SCR, but natural gas is the fuel expected to be used in normal operation. The amount of natural gas required to heat the 12,000 scfm of exhaust is 2.60 MMBtu/hr (based upon the measured propane usage during testing, then adjusted using 2,500 Btu/ft^3 propane with 1,031 Btu/ft^3 natural gas to calculate the natural gas usage). Also, in the proof-of-concept test, diesel engine generators were used to produce the electricity needed, but electricity from the local utility is expected to be used in normal operation. The diesel engine generators and propane were used due to the ALECS installation being temporary only for this proof-of-concept test and being located in a remote area of the rail yard.

Table 13. Utility, Energy, and Chemical Consumption Rates

Consumables	Quantity	Units
Electricity	328	kWh/hr
Natural Gas	2.60	MMBtu/hr
Water	180	gal/hr
Aqueous Urea (40%)	0.54	gal/hr
Sodium Hydroxide (30%)	0.0095	gal/hr

4.3 Waste Characterization

The solid waste produced by the ALECS and collected from the Preconditioning Chamber and the Cloud Chamber discharge was analyzed. The toxic chemicals and Title 22 metal compounds were below the detection limit of the laboratory. The only detectable compounds are shown in Table 14. The complete lab report is included in Appendix D.

Table 14. Solid Waste Analysis

	Units	Sample #1	Sample #2
Oil & Grease	mg/Kg	85,000	78,000
Total Recoverable Petroleum Hydrocarbons	mg/Kg	88,000	80,000
Zinc	mg/Kg	92	22

Solid waste accumulated from the ETS was estimated to be produced at a peak rate of 2.2 lb/hr. This estimate is based upon data collected by ACTI during the testing. Captured solid waste was stored in drums that hold around 400 pounds of material each. The filled drums were transported by an ACTI truck to an approved disposal site

The liquid wastewater was analyzed and the results are provided (as well as the solid waste analysis) in Appendix D. Liquid wastewater was being produced at a rate of 0.9 gal/hr. Analysis of the wastewater shows it could be considered safe enough to be discharged to a publicly owned treatment works, but local policies specific to each location will need to be identified.

4.4 Diesel Fuel Analysis

The test fuel for the GP38 was ultra-low sulfur diesel fuel meeting ARB regulations for sulfur and aromatic content. The sulfur limit is 15 ppm, and the limit on aromatic content is 10 percent unless the fuel is produced according to an approved alternative formulation. The test fuel for the Dash-8 was a diesel fuel that is actually supplied to Union Pacific line-haul locomotives outside California. This fuel was specified with sulfur content between 200 and 500 ppm.

Table 15 shows the results of analyses performed on each fuel sample. EF&EE collected fuel samples from each locomotive's fuel tank during the test program. The fuel tanks were sealed and labeled to ensure that fuel was not added to the tanks by mistake.

Table 15. Fuel Analyses

	Method	Dash 8	GP38
Carbon Content	D-5291	86.00%	86.10%
Hydrogen Content	D-5291	13.33%	13.73%
Nitrogen Content	D-5291	0.05%	0.06%
Sulfur Content (ppm)	D-4294	500	<150[1]

[1] This test did not have the resolution to verify 15 ppm sulfur content. However, the fuel was taken from the Roseville rail yard fueling system and all fuel dispensed in Roseville at the time met CARB diesel with a sulfur content of 15 ppm or less.

4.5 Noise Measurements

The locomotive noise measurements were measured at a point 30 meters perpendicularly away from the side of the locomotive with and without the bonnet attached to the stack(s). The decibel scale is logarithmic rather than linear. Hence a small reduction in decibels results in a fairly large percent reduction in sound energy. Table 16 shows the results of the noise measurements taken.

Table 16. Noise Measurements with and without the Bonnet in Place

	Average Sound Level (decibels)			Percent Reduction In Sound Energy
	w/o Bonnet	w/Bonnet	Reduction	
DASH-8: Notch 8	87.0	81.7	5.3	70%
DASH-8: Notch 5	84.5	77.7	6.8	79%
GP38: Notch 8	91.6	84.8	6.8	79%

4.6 Overall System Evaluation

Conventional stationary emission control technology has been demonstrated to be very effective in treating emissions from locomotive sources. The ECS demonstrated the ability to capture emissions from a single locomotive (at a time) while motionless and while moving. The proof–of-concept test utilized a system that was installed to handle a single locomotive at a time; a full-sized emissions capture system (ECS) with multiple locomotives was not tested.

5. Life Cycle Cost Analysis

5.1 Methodology

The life cycle cost analysis estimates the total cost of the ALECS incurred over the life of the system and is used along with the emission estimates to determine the system cost effectiveness per ton of pollutant reduced. The life cycle cost analysis entails Cost Element Definition, Data Collection, and Evaluation.

5.2 Cost Element Definition

Cost elements are broken down into Initial Capital Costs, Operating and Maintenance Costs including Utility/Energy Costs, Repair and Replacement Costs, Downtime Costs, Environmental Costs, and Salvage Value.

A) Initial Capital Costs include engineering and design (drawings and regulatory issues), bidding process, purchase order administration, hardware capital costs, testing and inspection, inventory of spare parts, foundations (design, preparation, concrete and reinforcing), installation of equipment, connection of process piping, connection of electrical wiring and instrumentation, one-time licensing/permitting fees, and the start up (check out) costs.

B) Operating and Maintenance Costs include items such as labor costs of operators, inspections, insurance, warranties, recurring licensing/permitting fees, and all maintenance (corrective and preventive maintenance). Also included are yearly costs of consumables such as the utility/energy costs (electricity, natural gas, and water) and chemical costs (such as sodium hydroxide and urea).

C) Repair and Replacement Costs are the costs of repairing and replacing equipment over the life of the ALECS. This would also include catalyst material replacement.

D) Rail yard impact costs include estimates of costs incurred by the Union Pacific Railroad. An example would be if the ALECS was shut down for repairs and locomotives that normally would be serviced or stored in a specific area needed to be relocated and serviced/stored elsewhere. Rail yard impact costs would also include the costs to change rail yard operations that are different from what is practiced today (including structural changes, if needed, to accommodate ALECS). For example, the additional time and costs (including labor) of rerouting locomotives to the ALECS area if the locomotives may not have been normally required to be moved. Locomotive downtimes can be very expensive to the rail yard and may result in loss of revenue. Costs may also be negative (a benefit to the rail yard) if the implementation of ALECS produced increased efficiencies such as decreased dwell time (time a locomotive is in the rail yard). At the current time, Union Pacific Railroad does not have an estimate (positive or negative) as to the effect ALECS would have on rail yard operations.

E) Environmental Costs are associated with the disposal of wastewater, solid waste, used chemicals, and used parts.

F) The Salvage Value of the system would be the net worth of the ALECS in its final year of the life cycle period. If the system can be moved and salvaged for useful parts/purposes, there would be a reduction in life cycle costs.

The estimates in this report are based upon data and observations taken during the operation and proof-of-concept testing of the ALECS.

5.3 Data Collection and Assumptions

Accuracy of input data is important to improve the certainty of the life cycle cost prediction. Data was obtained from stakeholders in this project (such as ACTI, UPRR, EF&EE, and the PCAPCD) to provide the most accurate information available. Where actual data were not available from the stakeholders, literature searches, theoretical calculations, and engineering estimates were utilized. The ETS would be common among installations at different rail yards, however, the ECS would need to be tailored to each specific installation dependent upon the size and activity of locomotives at each rail yard. However, the main ECS components would be common, just arranged to cover a different length or width of the section of rail yard being addressed. For estimating costs, an installation for the Western United States is assumed.

ACTI provided information on the initial capital costs (see Table 17). The costs include burden, markup, and taxes. Taxes do not include provisions for property taxes. The ECS is based upon the full scale deployment design of the concentric tube manifold subsystem shown Section 2.2. The estimates are based upon 12 bonnets installed for an ETS installed at the rail yard. The ETS equipment costs include a semi-automatic solid waste removal system that will replace the bag filter system that was used in the proof-of-concept test. A boost blower has been added to the Roseville proof-of-concept test design in order to compensate for the length of the full-scale ECS design.

The costs are based upon the assumption of reduced prices from multiple production runs of around 20 units, split between rail and marine applications

The Indirect Installation Costs were adjusted based on ACTI's experience in Roseville. As this system is duplicated in many locations, the required Engineering Support will become considerably less on each succeeding application, and most of the non-recurring engineering will only be needed for the first application. This also applies to some extent to the rest of the indirect installation costs as well. The construction, field expenses, and contractor fees are mostly included as part of the Equipment Costs, although a portion of these costs is still required for final placement and integration of these items.

The proof-of-concept test design utilized a filtration system to separate the particulate from the Preconditioning Chamber and Cloud Chamber Scrubber water for disposal. Figure 25 shows the originally white filters (Figure 26) that have turned black with use in the proof-of-concept testing.

The full scale deployment design would incorporate the Solid Waste Semi-Automatic Removal System shown in Figure 27 that would be able to process higher volumes of particulate with less labor and filter material/changes.

Table 17. ALECS Initial Capital Costs

	Qty	Units	Cost/Unit	Subtotal	Total
Equipment Costs					
ECS: Overhead Structure	1,200	feet	$ 933	$1,119,901	
ECS: Overhead Manifold	1,200	feet	$ 1,077	$1,292,193	
ECS: Bonnets	12	each	$ 57,431	$ 689,170	
ECS: Boost Blower	1	each	$ 19,383	$ 19,383	
ETS	1	each	$3,625,319	$3,625,319	
Emissions Monitoring	1	each	$ 518,378	$ 518,378	
Total Equipment Costs (Cp):				**$7,264,343**	
Shipping	3%	Cp	$7,264,343	**$ 217,930**	
				Purchased Equipment Cost (PEC):	**$7,482,273**
Direct Installation Costs					
ECS: Piers	24	each	$ 1,436	$ 34,458	
ECS: Assembly & Erection	1,200	feet	$ 144	$ 172,292	
ECS: Electrical	1	each	$ 43,073	$ 43,073	
ETS: Pads & Foundations	1	each	$ 107,683	$ 107,683	
ETS: Electrical	1	each	$ 93,325	$ 93,325	
ETS: Natural Gas/Propane/CNG	1	each	$ 43,073	$ 43,073	
ETS: Water	1	each	$ 1,436	$ 1,436	
ETS: Sewer (Industrial)	1	each	$ 8,615	$ 8,615	
Permits	1	each	$ 50,970	$ 50,970	
Infrastructure Design & Construction	1	each	$ 78,967	$ 78,967	
Trenching and Coring	1	each	$ 8,615	$ 8,615	
Consumables for Commissioning	1	each	$ 31,587	$ 31,587	
				Total Direct Costs (TDC):	**$ 674,094**
Indirect Installation Costs					
Engineering Support	0.5%	PEC	$7,482,273	$ 37,411	
Construction & Field Expenses	1.0%	PEC	$7,482,273	$ 74,823	
Contractor Fees	2.0%	PEC	$7,482,273	$ 149,645	
Start-up	0.5%	PEC	$7,482,273	$ 37,411	
Performance Test	0.5%	PEC	$7,482,273	$ 37,411	
Contingencies	2.5%	PEC	$7,482,273	$ 187,057	
				Total Indirect Costs (TIC):	**$ 523,759**
				Total Initial Capital Investment (TICI):	**$8,680,126**

Figure 25. Some Solid Waste Filters Used During the Demonstrating Testing

Figure 26. Clean Solid Waste Filter

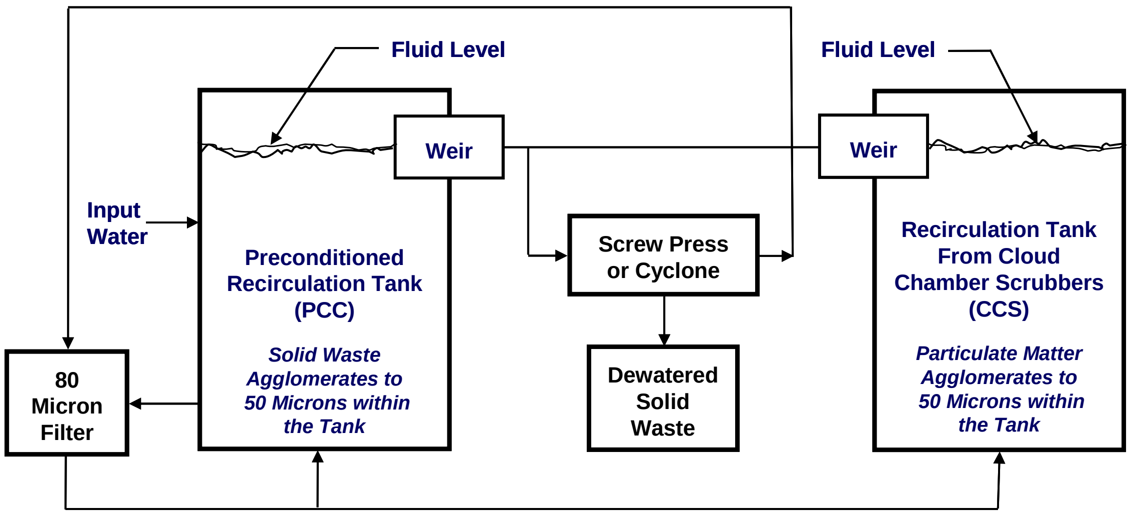

Figure 27. Solid Waste Semi-Automatic Removal System

The solid waste and particulate matter collected within the PCC and CCS recirculation tanks are removed (skimmed) from the surface using a Weir. ACTI experience has shown that the solid waste and particulate matter agglomerates within the tanks to a size of approximately 50 microns. Since the water in the tanks is turbulent, material does not tend to accumulate on the bottom.

The removed material is then sent to a screw press or cyclone which automatically removes much of the water. The removed water is returned to the appropriate recirculation tank, the solid material is then deposited into roll bins for removal and disposal. Analysis has shown the solid waste material to be non-hazardous.

The removed water is then filtered through an 80 micron filter prior to being returned to the appropriate recirculation tank. Filters are disposable and will be replaced every other month.

The annually recurring operation and maintenance costs are presented in Table 18. The consumables and utilities are based upon ALECS operating 96 percent of the maximum annual hours (ACTI estimate). The electricity and natural gas prices are based upon the Energy Information Administration's forecasted 2007 Industrial prices for the Pacific region. The SCR catalyst is estimated to be replaced every five years at a cost (fully loaded) of $86,146. The 5 year life of the catalyst is based upon the removal of sulfur and PM prior to the SCR which extends the life of the catalyst. The catalyst is assumed to not be replaced in the 20th year of the ALECS operation due to the end of its projected 20 year life. This catalyst replacement cost is annualized in the recurring operation and maintenance costs. It is assumed that there will not be a salvage value of the ALECS at the end of its useful life and any salvage value would be offset by any costs associated with shutting down the ALECS.

Burden and profit are not applied to the "Utilities" line items (e.g. electricity, natural gas, and water), as these will be supplied by the rail yard. However, maintenance and labor will be supplied by a third party operator/owner. ALECS will be staffed 24 hours a day, 365 days a year as shown in Table 18.

Table 18. ALECS Annually Recurring Operation and Maintenance Costs

	Usage Rate		Unit Cost		$/hr	$/year
Consumables/Utilities/Fees						
Sodium Hydroxide (30%)	0.0095	gal/hr	$ 1.65	/gal	$ 0.02	$ 132
Aqueous Urea (40%)	0.54	gal/hr	$ 1.86	/gal	$ 1.01	$ 8,462
Electricity	328	kWh/hr	$ 0.0747	/kWh	$ 24.50	$ 206,049
Natural Gas	2.60	MMBtu/hr	$ 7.20	/MMBtu	$ 18.69	$ 157,213
Natural Gas Meter Charge	1	meter	$ 11.51	/meter-day	$ 0.48	$ 4,201
Water	180	gal/hr	$ 1.66	/1000 gal	$ 0.30	$ 2,513
Liquid Waste	0.90	gal/hr	$ 0.34	/gal	$ 0.30	$ 2,563
Solid Waste	2.19	lb/hr	$ 0.051	/lb	$ 0.11	$ 935
Insurance	1	premium/yr	$ 33,863	/site	$ 3.87	$ 33,863
Labor						
Technician	1	Technician	$ 84,114	/year	$ 40.44	$ 84,114
Operator	4	Operators	$ 56,570	/year	$ 27.20	$ 226,279
Maintenance	2.0%	TICI	$ 8,680,126	/TICI	$ 19.82	$ 173,603
					Total Annual Recurring Operating Costs[1]:	**$ 899,926**

[1] An additional catalyst replacement cost (not included in the annual costs above) of $86,146 also occurs every 5 years. Cost is annualized in the economic analysis.

5.4 Evaluation

The total life cycle cost of the ALECS is based upon the discounted cash flow of costs in the future (which brings the costs to their present value), and the annualized payments of initial capital costs to account for the time value of money. The costs are summed to produce the total life cycle cost of the ALECS. The interest (discount rate) is assumed to be 4 percent based upon the value used in the Carl Moyer program (CARB, January 6, 2006). The system is designed and projected to have a life of 20 years (the EPA Air Pollution Control Cost Manual uses a 20 year economic lifetime for a SCR system) (EPA, January 2002).

The Initial Capital Investment of $8,593,980 (without the catalyst cost) is annualized with an adjustment for the time value of money (4 percent interest for 20 years) to be $632,360/year. The cumulative 20 year cost is $12,647,202.

The catalyst cost of $86,146 is annualized with an adjustment for time value of money (4 percent interest for 5 years) for the first 5 years. Each subsequent 5 year increment has a catalyst replacement cost reduced to the present value (from the year the catalyst is replaced) before adjusting for the time value of money. This results in a total catalyst cost of $287,727 over the 20 year life of ALECS. The summary of the components used to build up the catalyst costs are presented in Table 19.

Table 19. Summary of Catalyst Costs for ALECS

	Years 1 - 5	Years 6 – 10	Years 11 - 15	Years 16 - 20	Total
Catalyst Cost (2007$)	86,146	86,146	86,146	86,146	344,585
Year of Replacement		6	11	16	
Present (discounted) Value (2007$)	86,146	68,083	55,959	45,994	256,182
Adjusted for Time Value of Money (2007$)	96,754	76,466	62,849	51,658	287,727
Annualized Cost/year (2007$)	19,351	15,293	12,570	10,332	

The net present value (which accounts for the changes in value of money over time) of the operation and maintenance cost ($899,926/year) over the life of ALECS is $12,230,292.

The ALECS total life cycle cost over a 20 year period is $25,165,221. The summary of the annual costs (fully loaded with the burden, markup, and taxes) adjusted for the time value of money is shown in Table 20 and Figure 28.

Table 20. Summary of Annual Costs (2007$)

Year	Initial Capital Cost (w/o catalyst)	Catalyst Cost	Operation and Maintenance Cost	Total Cost
1	632,360	19,351	865,314	1,517,025
2	632,360	19,351	832,032	1,483,743
3	632,360	19,351	800,031	1,451,742
4	632,360	19,351	769,261	1,420,972
5	632,360	19,351	739,674	1,391,385
6	632,360	15,293	711,225	1,358,878
7	632,360	15,293	683,870	1,331,523
8	632,360	15,293	657,567	1,305,221
9	632,360	15,293	632,276	1,279,930
10	632,360	15,293	607,958	1,255,611
11	632,360	12,570	584,575	1,229,505
12	632,360	12,570	562,091	1,207,021
13	632,360	12,570	540,472	1,185,402
14	632,360	12,570	519,685	1,164,615
15	632,360	12,570	499,697	1,144,627
16	632,360	10,332	480,478	1,123,170
17	632,360	10,332	461,998	1,104,690
18	632,360	10,332	444,229	1,086,921
19	632,360	10,332	427,143	1,069,835
20	632,360	10,332	410,715	1,053,406
Total Cost	12,647,202	287,727	12,230,292	**$ 25,165,221**

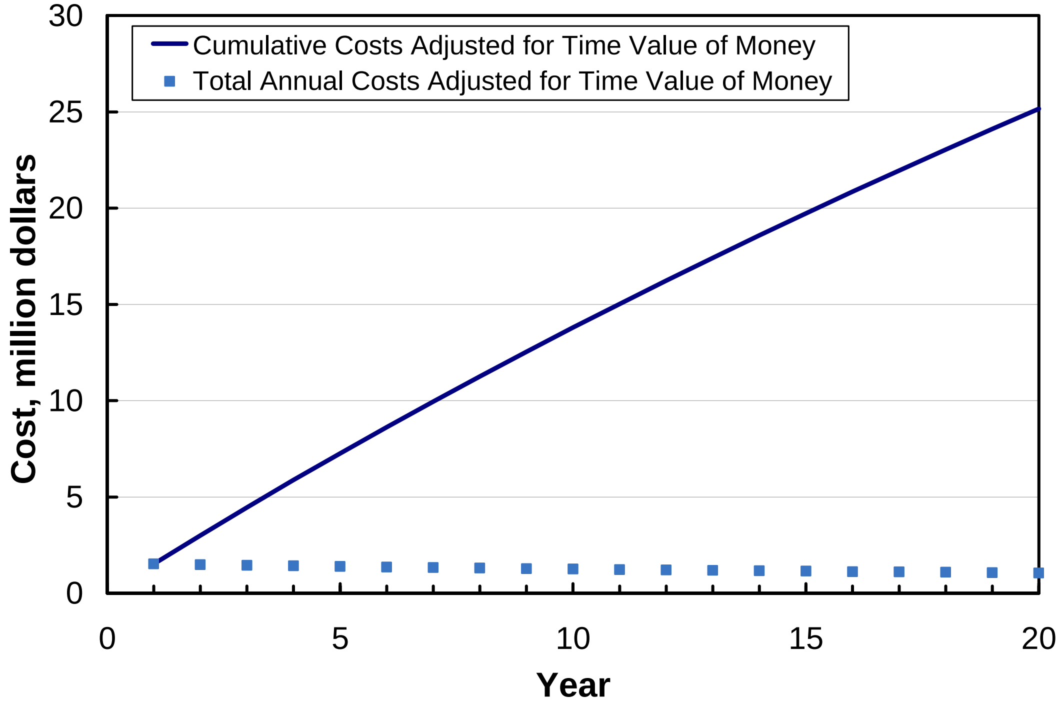

Figure 28. ALECS Annual Cash Flow and Cumulative Costs (2007$)

6. Cost Effectiveness

The cost effectiveness of ALECS is determined by dividing the total ALECS life cycle cost by the total weighted emissions reduced by ALECS over the life of the system. The use of weighted reduced emissions is based upon the Carl Moyer Memorial Air Quality Standards Program (CARB, January 6, 2006). The Carl Moyer program considers NO_x, THC and PM_{10} emission reductions in one calculation where weighting factors are applied. For NO_x and THC emission reductions, a weighting factor of one is used. CARB has identified particulate emissions from diesel-fueled engines as toxic air contaminants, and believes emission reductions of PM_{10} should carry additional weight in the calculation because, for an equivalent weight, these emissions are more harmful to human health. CARB uses a PM10 weighting factor of 20. The Carl Moyer method utilizes the Annualized Cash Flow method which multiplies the initial capital cost by a capital recovery factor to obtain an equivalent end of year annual capital cost payment.[1] This report utilizes the annualized capital costs adjusted for the time value of money and the Discount Cash Flow method for future costs which calculates the cost by determining the present value of the costs of buying, operating, and maintaining the equipment over the life of the equipment (see life cycle costs analysis above).

The weighted cost effectiveness formula for ALECS analysis is:

$$\frac{\text{Total Life Cycle Cost (2007\$)}}{(NO_x + \text{THC} + 20{*}PM_{10})\ \text{(tons reduced over life of equipment)}}$$

The emissions measurements from this proof-of-concept test are based upon just two locomotives (the Dash-8 and the GP38) and may not be representative of all Dash-8 (line-haul) or all GP38 (switcher) locomotives. The emissions reduced in the rail yard application will be highly dependent on the specific details of each application. In an attempt to bound the possible uses in a rail yard, two examples using only two locomotives are presented. One example case utilizes all idling, Tier 2 locomotives that will produce the lowest emissions for treatment by the ALECS. The other example case, representing high emissions, assumes Tier 0 locomotives operating at various conditions.

Tier 0 Dash-8 emissions data were obtained from CARB (based upon GE certification data for C40-8) as compiled for the Roseville rail yard health risk assessment study (CARB, October 14, 2004) and should be more representative of the locomotives operating at the rail yard. Tier 2 emissions data were estimated based upon EPA engine certification data for the GE engine family "6getg0958efb" (EPA website, March 2007). These emission factors are presented in Table 21. SO_x emission factors were not used because Tier 0 data were not available

Without further information on the estimated number of locomotives and their throttle settings in a specific area of the rail yard, the following 4 scenarios (the first 3 scenarios apply to the Tier 0 locomotives) in Table 22 were created. All of these scenarios were designed to fully use the

[1] The Moyer method does not consider annual operating and maintenance costs.

12,000 scfm capability of ALECS. For example, 6 Tier 2 engines at idle would fully use the systems capability or only 1 Tier 0 locomotive at notch 8.

Table 21. Locomotive Emission Factors

Locomotive	Throttle	Exhaust (scfm)[1]	PM (g/hr)	NO_x (g/hr)	THC (g/hr)
Tier 0	8	12,077	615	29,527	861.21
	5	7,176	327.68	14,746	655.36
	idle	2,000	36.95	746.49	268.65
Tier 2	idle	2,000	25.1	747.2	71.5

[1] Exhaust flow rate for Tier 0 at throttle notch 8 and 5 are from proof-of-concept testing. The idle exhaust flow rates are estimated.

Table 22. Locomotive Scenarios

Scenario #	Locomotive	Number of Locomotives			Total Exhaust (scfm)
		Notch 8	Notch 5	Idle	
1	Tier 0	1	-	-	12,077
2	Tier 0	-	1	2	11,176
3	Tier 0	-	-	6	12,000
4	Tier 2	-	-	6	12,000

Applying the emission factors from Table 21 and this proof-of-concept's overall control efficiencies from Table 12 (the NO_x control efficiency was reduced 1.5 percent, from 97.8 to 96.3 percent, to account for catalyst degradation over time) to the scenarios produced the total emissions controlled in Table 23 if each scenarios were individually running 100 percent of the time.

Table 24 shows the maximum available controlled emissions if ALECS was able to run at full capability (12,000 scfm) 100 percent of the time for each of the bounding cases (Tier 0 and Tier 2). The Tier 0 example case utilizes all GE Dash-8 locomotives with a mix of notch 8 (10 percent), notch 5 (20 percent) and idling (70 percent) operating conditions. The higher notch running of the locomotives represents a situation where the ALECS is situated in a location where there is diagnostic and load testing performed. The testing is supplemented with idling to keep the ALECS fully employed.

No deterioration factors (DF) are used for the Tier 2 locomotives over the 20 year life of the ALECS system.

Table 23. Maximum Controlled Emissions for Each Scenario

Scenario #	PM (g/hr)	NO_x (g/hr)	THC (g/hr)
1 (Tier 0)	566	28,440	540
2 (Tier 0)	370	15,640	748
3 (Tier 0)	204	4,314	1,010
4 (Tier 2)	139	4,318	269

Table 24. Maximum Annual Controlled Emissions

Scenario #	Hours/yr	PM (ton/yr)	NO_x (ton/yr)	THC (ton/yr)
1 (Tier 0)	876	0.55	27.46	0.52
2 (Tier 0)	1,752	0.71	30.21	1.44
3 (Tier 0)	6,132	1.38	29.16	68.83
Total Tier 0	**8,760**	**2.64**	**86.83**	**8.80**
Total Tier 2	**8,760**	**1.34**	**41.70**	**2.60**

Deterioration factors (DFs) were applied to the emission factors for the Tier 0 case. Roseville rail yard is a major service center for Union Pacific where locomotives are brought for diagnostics and repair. Some of these locomotives have been observed to produce visible emissions not common to well-running engines. It is anticipated that some of these abnormally high emission locomotives would be connected to the ALECS during diagnostics.

The Dash-8 locomotive tested in this proof-of-concept project was obtained from the normal operational fleet, but was suspected of having higher than average emissions. When compared to the certification data for this locomotive type (see Table 21), the emissions for PM and NO_x were considerably higher. The DFs used for this Tier 0 example case were set at the average of the certification data and the test results obtained in this project. The project PM data were 229 percent greater than the certification data with the NO_x data 159 percent greater (THC was 44 percent). The DFs applied for PM is 1.64 with 1.29 applied to NO_x (THC factor is not applied).

Table 25. Tier 0 Deterioration and New Engine Introduction Factor

	PM	NO_x	THC
% Greater than Certification	229%	159%	-
Deterioration Factor	1.64	1.29	1
Reduction due to New Engines	14%	14%	13%
Adjusted Deterioration Factor	**1.42**	**1.12**	**0.87**

To recognize that over the next 20 years the fleet of locomotives is expected to trend toward lower emissions as new locomotives are added and the oldest locomotives are retired, a reduction factor was added to represent the upgrading of the fleet. This information was obtained from an EPA projection that lists fleet average emission factors by year going into the future (EPA, December 1997). Looking at the reduction projected from 2008 to 2028 and averaging over the 20 years gives emission factor reductions of 14 percent for PM, 14 percent for NO_x, and 13 percent for HC. Combining the DF and fleet average reduction into a single factor gives the following factors used for this analysis:

For the cost effectiveness calculations, the ALECS is assumed to have a 96 percent utilization factor (ACTI estimate) and the emission estimates for the Tier 0 example are shown in Table 26 and 27. The adjusted emissions shown in these tables include the factor of 20 for the PM_{10} adjustment and the adjusted DFs shown in Table 25 for PM10, NO_x and THC.

Table 26. Annual Tier 0 Controlled Emissions with ALECS at 96 Percent Utilization

Scenario #	Hours/yr	PM (ton/yr)	NO_x (ton/yr)	THC (ton/yr)
1	841	0.52	26.36	0.50
2	1,682	0.69	29.00	1.39
3	5,887	1.32	27.99	6.56
Sum	8,410	2.53	83.35	8.44
Adjusted Emissions		71.87	93.23	7.34

Table 27. Annual Tier 2 Controlled Emissions with ALECS at 96 Percent Utilization

Scenario #	Hours/yr	PM (ton/yr)	NO_x (ton/yr)	THC (ton/yr)
4	8,410	1.29	40.03	2.49
Adjusted Emissions		25.72	40.03	2.49

The total weighted controlled PM, NO_x, and THC emission for Tier 0 is 172.4 tons/yr with Tier 2 estimate of 68.2 tons/yr. SO_x emissions reductions are not considered in these estimates. Over the total 20 year life of the ALECS, the total weighted emissions reduced ranges from 1,365 tons to 3,449 tons. The resulting cost effectiveness is estimated to range from $18,437/ton to $7,297/ton of weighted pollutant reduced. Figure 29 shows the cost effectiveness curve over the 20 year projected life of the ALECS. The point to the furthest left of the figure represents Tier 2 locomotives operating only in idle mode (with a 96 percent ALECS uptime factor). The point on the curve to the furthest right of the graph represents Tier 0 Dash-8 locomotives operating 10 percent of the time at notch 8, 20 percent at notch 5, and the remaining 70 percent of the time at idle (also applying a 96 percent ALECS uptime factor and DFs). The single magenta point (square shape) is an estimated midpoint to be used for sensitivity analysis.

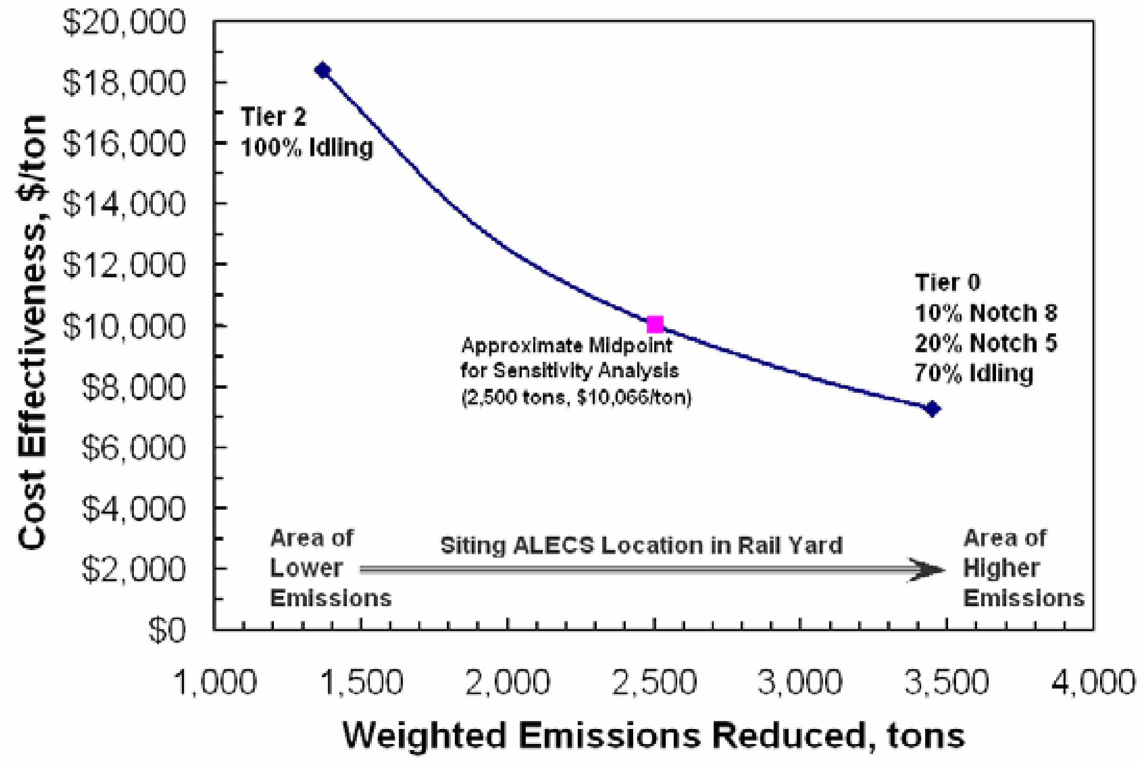

Figure 29. ALECS Cost Effectiveness

Figure 29 highlights the importance of installing the ALECS in an area of the rail yard where there are locomotives operating in higher notch settings. Installing the ALECS in an area where emissions reductions fall on the right side of the figure would result in better cost effectiveness than locations with emissions that fall further to the left. Higher emissions would result from higher engine settings than at idle, therefore, it is possible for less engines running at higher notch settings to have higher total emissions than if more engines were running, but were only idling. Careful analysis of the locomotive mix and how many engines are running in specific areas of the rail yard is important, but also knowing what notch setting and for how long each engine is running would also be important in determining where the ALECS should be located to maximize emissions reductions and provide best ALECS cost effectiveness.

Sensitivity analysis on the cost effectiveness was performed on the approximate midpoint according to the hypothetical base case parameters listed in Table 28. The results are graphed in the tornado chart in Figure 30.

Table 28. Parameters Used for the Cost Effectiveness Sensitivity Analysis

	Better Cost Effectiveness	Approximate Midpoint Case	Worse Cost Effectiveness
Throttle Notch Positions	10% N8, 20% N5, 70% Idle	5% N8, 10% N5, 85% Idle	100% Idle
Emissions Reduction Rate	150 ton/yr	125 ton/yr	100 ton/yr
System Utilization Rate	100%	96%	70%
ALECS Lifetime	25 years	20 Year Life	15 years
Interest (Discount Rate)	-	4%	6%

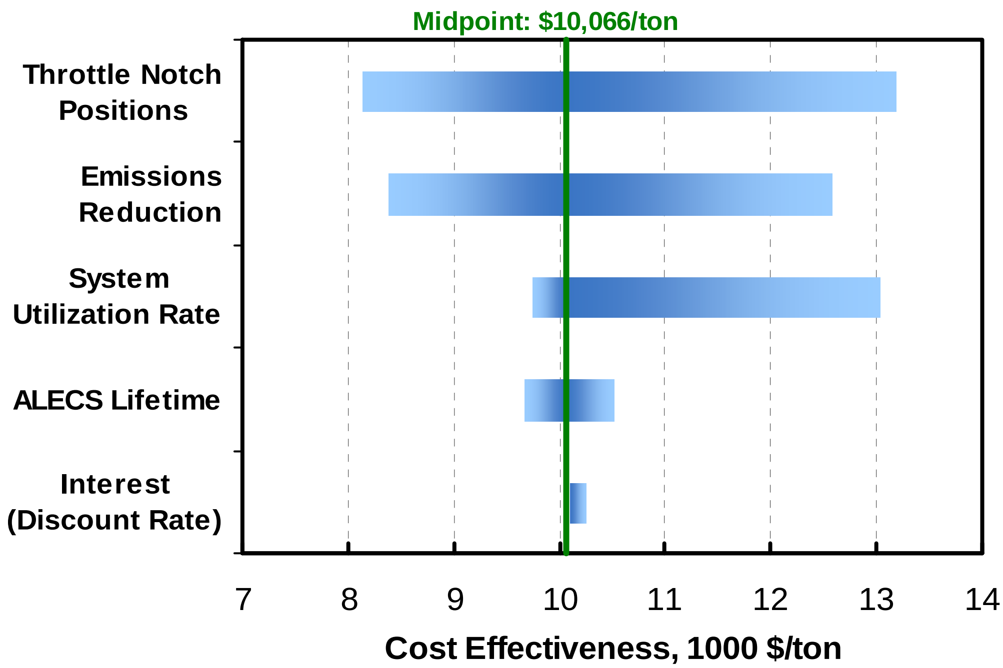

Figure 30. Cost Effectiveness Sensitivity on Midpoint

The estimated 96 percent system utilization rate is based upon locomotive emissions being generated 100 percent of the year (based upon the scenarios described above) and the ALECS being available 96 percent of the time. The minimum cost effectiveness value (better) was based on the ALECS being available 100 percent of the time. The maximum cost effectiveness value (worst) is based upon a 70 percent system utilization rate which is not only based upon the ALECS availability (ACTI expects ALECS to be available at least 96 percent of the time), but it also incorporates whether there are emissions being generated. The 70 percent would represent the ALECS being available and exhaust emissions are also being generated at the same time. A 30 percent increase in cost effectiveness would be due to a drop in system utilization rate to 70 percent. This highlights the importance of installing the ALECS in a busy area of the rail yard where there would be a high concentration of locomotives generating emissions.

The locomotive throttle notch positions were examined at 100 percent idling for the maximum cost effectiveness value and 10 percent at notch 8 with 20 percent at notch 5 for the minimum.

The increase in time at higher notch settings (with 70 percent of the remaining time spent idling) resulted in a 19 percent reduction in cost effectiveness. At 100 percent idling, the cost effectiveness jumps up 31 percent. Understanding the operational modes of the locomotives is important because they have a large impact on the cost effectiveness. Preference in placement of the ALECS would be in areas where locomotives would run at higher notches than areas where locomotives would only idle.

An increase of 20 percent of the pollutants reduced from the baseline resulted in a 17 percent reduction in cost effectiveness. A 20 percent reduction in pollutants from the base case increased the cost effectiveness by 25 percent.

Increasing the interest (discount rate) from the baseline of 4 percent (Moyer guideline) to 6 percent, results in a 2 percent higher cost effectiveness value. Analysis of interest rates less than 4 percent were not performed.

The ALECS was designed for a 20 year life, but if the system does not run after 15 years, the cost effectiveness increases 5 percent to $10,521/ton. If the system runs for 25 years, the cost effectiveness drops down 4 percent to $9,663/ton.

7. Summary/Next Steps

7.1 Summary

This project was a "proof-of-concept" effort designed to demonstrate the possible effectiveness of one set of stationary air pollution control equipment to capture and treat emissions from locomotives that are temporarily idling while sitting on a ready track, being prepared for servicing, being serviced, or undergoing engine load tests. The equipment was to be evaluated for effectiveness in capturing and treating PM, NO_x, SOx, and VOC emissions from such locomotives. The specific objectives of this proof-of-concept project and its accomplishments are summarized in Table 29.

Table 29. Summary of Project Objectives and Accomplishments

OBJECTIVE	ACCOMPLISHED?
Objective 1: Demonstrate the Possible Effectiveness of Stationary Control Equipment on Locomotive Exhaust: This proof-of-concept test of the ALECS equipment should quantify the overall capture and control efficiency of particulate matter (PM), NO_x, SO_x, and total hydrocarbons (THC) in actual locomotive exhaust in a rail yard environment. Locomotive engines in common use come in two distinct technologies; two-stroke and four-stroke. This proof-of-concept test will test one engine of each technology; a GP38 locomotive operating on ultra-low sulfur (15 ppmw) fuel, and a Dash-8 locomotive operating on a fuel with a sulfur content between 200 ppmw and 500 ppmw. Sound measurements will be taken with and without the control equipment to determine the extent of noise reduction due to the control equipment (sound measurements added during the project). Emissions testing will be conducted according to a test protocol developed for this project. The test protocol should prescribe accepted test methods appropriate to the pollutants being measured. The protocol will be reviewed by the air districts, CARB, and EPA. The testing will be conducted on the locomotive before the control equipment and upon exit from the control equipment and will determine emissions on a concentration and mass basis.	**Overall control efficiency:** ☑ **Accomplished** **Overall capture efficiency:** ☒ **Partially Accomplished:** Complete capture efficiency determination will require assessment of emission capture system functionality. Proof-of-concept project only tested one locomotive at a time in either motionless or short (50 feet) distance motion. **Testing according to protocol:** ☑ **Accomplished** (but note that emissions sampling at the locomotive stack was of questionable value)
Objective 2: Demonstrate the Attachment Scheme Between the Locomotive and the Stationary Control Equipment: Since a rail yard is a busy place where efficiency of operations is important, the attachment of the emissions control equipment to the locomotive must be quick, simple, and safe to the operating personnel. The operation of the ALECS must absolutely not impede the fluidity of normal railroad operations in any manner. Attachment, detachment, and capture efficiency will be demonstrated on locomotives with one and two emission stacks. During the emissions testing phase of this project, multiple attachments and disconnects shall be performed to demonstrate this capability. Rail yard personnel shall be given a chance to operate the attachment controls.	**Demonstrated on locomotives with one and two emission stacks:** ☑ **Accomplished** **Multiple attachments and disconnects:** ☑ **Accomplished** **Rail yard personnel given chance to operate the attachment controls:** ☒ **Not Accomplished**

Table 29. Summary of Project Objectives and Accomplishments (concluded)

OBJECTIVE	ACCOMPLISHED?
Objective 3: Demonstrate the Capability of Some Locomotive Movement While Connected to the Control Equipment: One of the design features of the ALECS is to allow movement of the locomotive along the track for a prescribed distance while connected to the emissions control equipment. During the emissions testing, some portion of the testing on each locomotive shall be conducted with the locomotive connected to the stationary control equipment and the locomotive moving to demonstrate this capability while fully capturing the exhaust from the engine in the locomotive.	**Testing while motionless and while moving:** ☑ **Accomplished**
Objective 4: Develop Improved Information on Capital Cost, Operating Procedures, and Operating Costs: The underlying purpose of this proof-of-concept test project is to provide information on performance, operation and cost of using stationary emissions control equipment to treat locomotive exhaust in rail yards that will enable the railroad and equipment suppliers to make business decisions on moving forward in deploying this type of equipment. During the installation and operation of the ALECS, information shall be collected and recorded that will enable capital and life cycle costs to be generated. Rail yard facility requirements for infrastructure and support utilities will be defined. These cost estimates shall be documented in the final report. Railroad personnel shall be instructed on operation and maintenance of the ALECS during the proof-of-concept project, and will provide to the PCAPCD estimates for all costs for impacts to yard or system operations (either capital or operating) are included in the final accounting. These cost estimates will be included in the project final report. The ALECS to be used for this proof-of-concept test is borrowed from another project where the equipment size was optimized for another application. As part of this objective, the cost of equipment appropriately sized and ALECS designed to serve the J. R. Davis Rail Yard will be estimated**.**	**Information collected to estimate cost.** **Rail yard infrastructure defined:** ☑ **Accomplished** **Cost estimates shall be documented:** ☑ **Accomplished** **Railroad personnel instructed on operation and maintenance of the ALECS:** ☒ **Not Accomplished** **Railroad provides estimates for all costs:** ☑ **Accomplished** **Cost estimates for rail yard impacts included in the project final report:** ☒ **Not Accomplished** **Cost of appropriately sized equipment:** ☑ **Accomplished**
Objective 5: Document Test Results and Project Findings in a Final Report: Since this proof-of-concept test project has, as one purpose, the generation of information on performance and operation of the ALECS sufficient to allow railroads to make business decisions on use of this stationary control equipment on their rail yards, the project results will be documented in a final report. The final report will include, as a minimum, details of the locomotives tested, configuration of the test setup, test equipment, test conditions, and test methods, logistic and operation issues identified during project implementation, and emission (and noise) test results before and after the control equipment.	**Information sufficient to allow railroads to make business decisions:** ☒ **Not Accomplished** **The final report details on test:** ☑ **Accomplished**

Table 30 summarizes the overall average pollutant control efficiencies of ALECS. The range of estimated emission reductions based upon two scenarios are presented in Table 31. ALECS installation in a rail yard is expected to yield emission reductions between the two assumptions, depending on the specific application.

Table 30. Summary of Pollutant Control Efficiencies

	NO_x	THC	PM	SO_2
Overall Average Control Efficiency[1]	97.8%	62.7%	92.1%	97.3%

[1] ALECS proof-of-concept test at Roseville rail yard

Table 31. Range of Estimated Emission Reductions (tons/yr)

	NO_x	HC	PM
Mixed Loads Tier 0 Emissions	83.4	8.44	2.53
Idling Only Tier 2 Emissions	40.0	2.49	1.29

The fully loaded total initial capital cost of the ALECS (for an estimated 12 bonnet system) is $8,680,126 with an annual operational cost estimate of $899,926 (not including the recurring $86,146 catalyst replacement every 5 years).

The total weighted controlled PM, NO_x, and THC emissions reduced over the 20 year life of ALECS is estimated to range from 1,365 tons to 3,449 tons. The resulting cost effectiveness ranged between $18,437/ton in the all idling mode to $7,297/ton of weighted pollutant reduced in the mixed mode of a combination of locomotives at idle and at higher loads.

Noise measurements made with, and without the bonnet attached to the locomotive, yielded noise reductions of 5.3 to 6.8 decibels, representing noise energy reductions of 70 to 79 percent.

7.2 Next Steps

While the ALECS proof-of-concept test mostly met the project objectives and yielded valuable information in confirming that the system is capable of capturing and treating locomotive emissions, there remains additional work in selected areas in order to support fielding a system in a rail yard with the anticipation of maximizing the ALECS potential in cost effective emissions reductions. The next steps towards possible implementation of the technology in a working rail yard are depicted in Figure 31, which identifies those areas where additional work is needed. It is envisioned that these steps, which may be viewed as pathways or tracks that should be followed in parallel, will yield more refined information in order to make implementation decisions. These tracks include public policy leadership, identification of a specific rail yard site for the initial system deployment, further technical demonstration, development of financial mechanisms for the funding of systems, and community benefits.

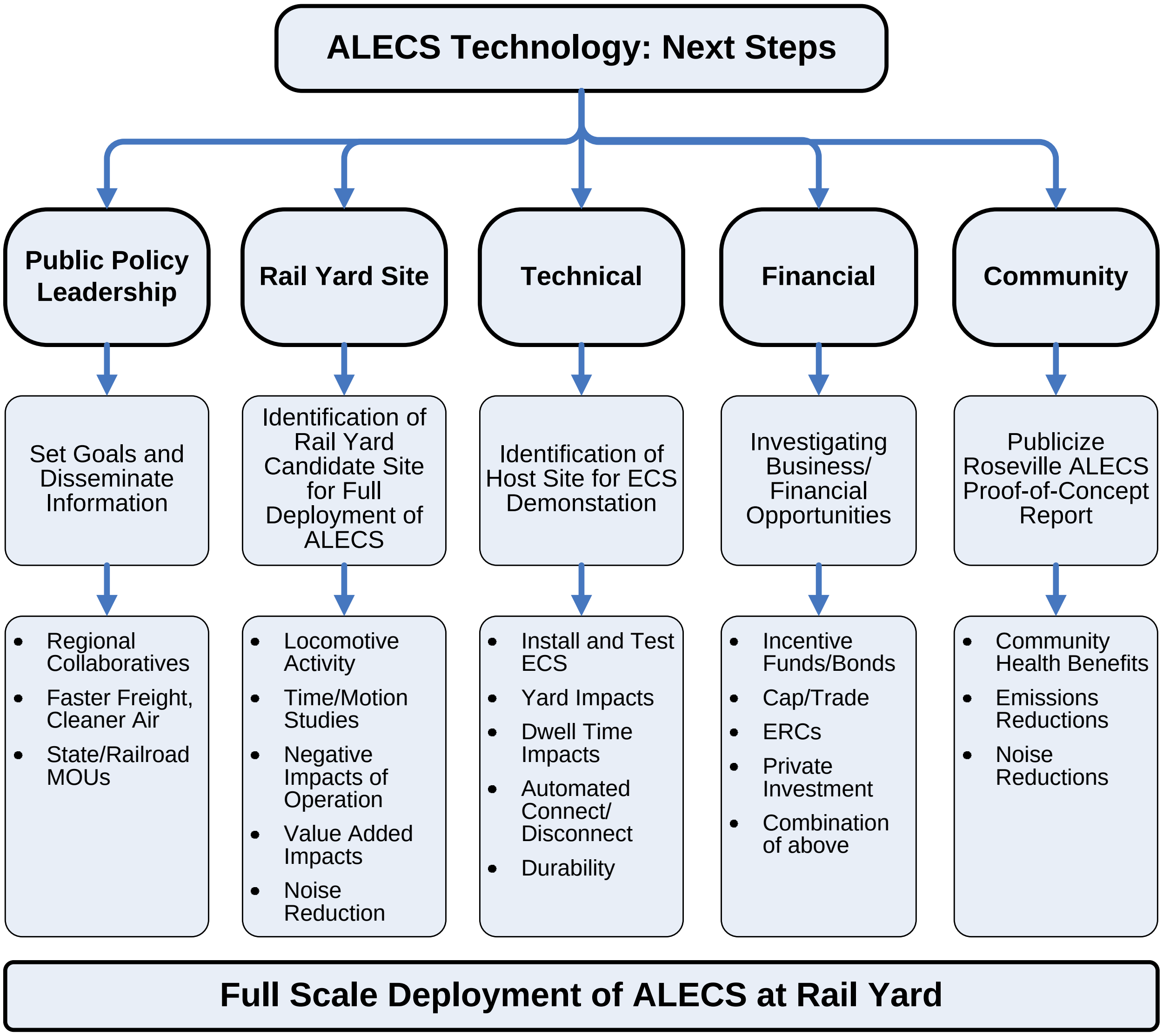

Figure 31. Next Steps Pathways

7.2.1 Public Policy Leadership

Government encouragement of utilization of this type of control equipment to reduce criteria and hazardous emissions from rail yards can have a positive effect on the railroad companies. Public agencies can encourage use by setting goals through regional diesel collaboratives and disseminating information in conferences like Faster Freight and Cleaner Air. State environmental agencies can encourage proliferation of this technology through agreements with the railroad companies which among other strategies to reduce rail emissions, includes implementation of the ALECS technology. Local air districts that have concerns over rail yard emissions in their territory can develop agreements with the railroad companies to utilize this technology in appropriate locations.

7.2.2 Rail Yard Site

Identification of the specific location of the initial full-scale system installation is critical. The operational experience of the first system will greatly influence the possibility of the installation of additional systems. Key considerations in choosing the location of the system in the rail yard are a continuous supply of an adequate number of running locomotives to keep the capacity of the ALECS fully utilized while not requiring additional effort from rail yard workers to route locomotives to this location.

It is recommended that the initial system deployment be at the J. R. Davis Rail Yard in Roseville, California. Some rail yard personnel are somewhat familiar with the ALECS and there are a number of potentially suitable sites for the system. Figure 32 is an aerial view of the rail yard with a number of potential sites labeled. Figure 33, Figure 34, and Figure 35 are photographs of potential ALECS locations in the diagnostics area of the diesel shop, the ready tracks, and the sanding station.

Figure 32. Aerial View of Potential ALECS Locations

Figure 33. Diagnostics Area of Diesel Shop

Figure 34. Ready Tracks

Figure 35. Sanding Stations

UPRR will need to perform an analysis of candidate locations to determine if current locomotive activity can support a high utilization factor for an ALECS at that location. Parameters to be considered are numbers of operating locomotives at the site over time, quantity of idle, diagnostic, and load testing conducted at that site, and typical mix of locomotive types using the site. For the more promising sites, UPRR should perform an in-depth time/motion study of the activity at the site and identify any operational changes that could improve the efficiency of the site operation using the ALECS. As part of these studies, UPRR should consider opportunities to use the capabilities of the ALECS to improve their rail yard efficiency and operations and reduce locomotive maintenance dwell time. Examples of these capabilities would be to utilize the emissions measurement function of the ALECS to aid in engine diagnostics, use particulate matter measurements to identify engines that have excessive visual emissions and need repair (higher levels of PM may be an indication of leaky fuel injectors), and perform high power load testing and diagnostics under the ALECS bonnets to reduce noise. Noise is a nuisance issue with the residential neighbors in Roseville.

7.2.3 Technical

Along a technical track, the proof-of-concept test program identified that additional demonstration is required for a redesigned trolley/bonnet and overhead manifold concept capable of hosting multiple locomotives. While a full-scale ALECS would include 12 trolley/bonnets and about 1,200 feet of overhead structure and collection manifold, it is recommended that approximately a one-half size subsystem should be installed and tested. The test system would not include the emissions control components, just the emissions capture subsystem. Any potential user of this system would require to see this demonstrated to evaluate automated connect/disconnect of multiple locomotives, impacts on the yard workflow and efficiency, and durability of the ECS components. This demonstration is estimated to cost $1.5 million. Funding for this demonstration is an open issue at this time. If possible, this demonstration should be conducted at a rail yard site with high potential to host a permanent ALECS installation.

7.2.4 Financial

There may be a number of options for funding the installation of ALECS systems in rail yards. In addition to the obvious option of railroad capital investment, there may be opportunities for incentive funds from state programs, private investment, cap/trade programs, and emission reduction credits. These funding options should be explored in parallel with the other next steps tracks.

Emission reduction credit (ERC) generation is an interesting funding option. Currently, the rules of most, if not all, California air districts are not structured in a way that would allow this type of credit generation. However, the ALECS can likely meet the general criteria for establishing ERCs. Noteworthy are the facts that the emission reductions from an ALECS are real and surplus. Surplus generally means that the emission reductions are not mandated by law, regulation or planned into the SIP; and the historical emissions are included in the state inventory. The California Air Pollution Control Officers Association (CAPCOA) has initiated an effort to develop protocols for non-traditional ERC generation. Currently, three pilot projects are proceeding, including one that includes the ALECS concept. PCAPCD is taking the lead on the rail yard stationary equipment ERC protocol development. EPA, CARB, and the air districts are involved in this effort. The goal of the effort is to produce a model protocol, approved by EPA and CARB, that can be adopted as a rule by the air districts. In the Roseville area, a number of industrial companies have expressed interest in possibly funding installation of an ALECS in order to have a claim on the ERCs generated.

Private investment and ownership of a system is another financial model that has potential to fund the installation of an ALECS. In this model, a third party company would own and maintain the system and lease its use to the railroad.

7.2.5 Community

Communities that are adjacent to rail yards are becoming more aware of the potential health impacts of rail yard emissions and more active in complaining of noise from the yard. In California, through the agreement between the major railroads and the California Air Resources Board, health risk assessments will soon be made public for the larger yards in the state. A community track of next steps should publicize the benefits of the ALECS in reducing diesel particulate emissions (and associated reduction in health risk) and the potential noise reduction of using the system on locomotives being tested at high power.

8. List of Acronyms

ACTI	Advanced Cleanup Technologies, Inc.
ALECS	Advanced Locomotive Emission Control System
CAPCOA	California Air Pollution Control Officers Association
CARB	California Air Resources Board
CCS	Cloud Chamber Scrubber (subsystem of ETS)
CEMS	Continuous Emission Monitoring System
CO	Carbon Monoxide
CO_2	Carbon Dioxide
Cp	Total Equipment Costs
DF	Deterioration Factor
ECS	Emissions Capture Subsystem
EF&EE	Engine, Fuel, and Emissions Engineering, Incorporated
EIB	Emissions Intake Bonnet
EMD	General Motors Electro-Motive Division
EPA	U.S. Environmental Protection Agency
ERC	Emission reduction credit
ETS	Emissions Treatment Subsystem
F	Fahrenheit
ft3	Cubic Feet
gal	Gallons
GE	General Electric
hr	Hour
ID	Induced Draft
ISO	International Standards Organization
kWh	Kilowatt Hours
lb	Pounds
mcf	Thousand Cubic Feet
MMBtu	Million British Thermal Units
MOU	Memorandum of Understanding
N_2O	Nitrous Oxide
NH_3	Ammonia
NO	Nitric Oxide
NO_x	Oxides of Nitrogen
O_2	Oxygen
OCU	Operational Control Unit of the ETS
PCAPCD	Placer County Air Pollution Control District
PCC	Preconditioning Chamber (subsystem of the ETS)
PEC	Purchased Equipment Cost
PM	Particulate Matter
$PM_{2.5}$	Particulate Matter less than or equal to 2.5 microns
PM_{10}	Particulate Matter less than or equal to 10 microns
ppm	parts per million
RAVEM	Ride-Along Vehicle Emissions Measurement system
SCAQMD	South Coast Air Quality Management District
scfm	Standard Cubic Feet per Minute

SCR	Selective Catalytic Reduction
SMAQMD	Sacramento Metropolitan Air Quality Management District
SO_2	Sulfur Dioxide
SO_x	Oxides of Sulfur
THC	Total Hydrocarbons
TICI	Total Initial Capital Investment
UPRR	Union Pacific Railroad Company

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Appendix A. Test Plan

J.R. DAVIS RAILYARD

ADVANCED LOCOMOTIVE EMISSION CONTROL SYSTEM (ALECS) DEMONSTRATION PROJECT

EMISSION TESTING PROTOCOL
VERSION 2.1
MAY 25, 2006

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1. INTRODUCTION

The Union Pacific Railroad's J.R. Davis Railyard has been determined to be a significant emissions source for diesel particulate matter (PM) and other toxic air contaminants related to locomotive emissions. An agreement between the Placer County Air Pollution Control District (APCD) and the Union Pacific Railroad Company includes a mitigation plan for reducing diesel particulate emissions from the railyard. This plan includes consideration of stationary air pollution control equipment to capture and treat emissions from stationary locomotives in the railyard while idling or undergoing engine load tests. To carry out this part of the plan, the APCD has initiated a project to demonstrate the Advanced Locomotive Emission Control System (ALECS).

The ALECS demonstration is a public-private collaborative project involving many parties, including the APCD, U.S. Environmental Protection Agency, Sacramento Metropolitan Air Quality Management District, Union Pacific Railroad, Advanced Cleanup Technologies Inc., the South Coast Air Quality Management District (AQMD), the California Air Resources Board, and the City of Roseville. Engine, Fuel, and Emissions Engineering, Inc. (EF&EE) has been tasked with carrying out the emissions measurements under a contract with the South Coast AQMD.

The ALECS is a system designed to control emissions from locomotives by capturing the exhaust stream from their engines and treating it to remove most harmful pollutants. The system includes a set of stationary emissions control equipment connected to an articulated bonnet or hood. The bonnet is designed to capture locomotive exhaust, delivering it to the ground-mounted emission control system by means of a flexible duct. The bonnet or hood remains attached while the locomotive is moving along the track to the extent of the flexible duct.

The emissions control equipment consists of a sodium hydroxide wash to remove sulfur dioxide (SO_2), a dual chamber cloud chamber scrubber for particulate matter (PM) removal, followed by a Selective Catalytic Reduction (SCR) reactor using urea as the ammonia source for oxides of nitrogen (NOx) reduction. The demonstration system is designed to treat exhaust flows between 2,000 and 12,000 standard cubic feet per minute (scfm).

1.1 OBJECTIVES

The objectives of the test program are:

- To measure and document the effectiveness of the ALECS system in controlling locomotive emissions of diesel particulate matter (PM), oxides of nitrogen (NOx) and other pollutants of concern under typical railyard operating conditions;
- to assure that the emission control process does not generate excessive amounts of other pollutants, such as ammonia; and
- to quantify the water and chemical consumption, operating costs, and waste generated by the ALECS system.

1.2 OVERVIEW OF THE TEST PROGRAM

The test program will include emission measurements at three locations: in the locomotive stack(s), at the inlet to the ground-mounted emission control system, and at the outlet from the emission control system**.** The effectiveness of the ALECS emission control system will be determined by comparing the mass emissions measured both at the locomotive stack and at the inlet to the emission control system with those measured at the system outlet to the system. Comparing the emissions measured at the locomotive stack to those at the inlet will make it possible to identify any effects on pollutant mass or characteristics due to the overhead manifold system.

The test program will include two locomotives, each of which will be operated in a defined sequence of test modes. Each of the test sequences will be repeated three times. Testing is scheduled to begin July 31, and will take two weeks (eight testing days, plus setup time) to complete.

Pollutants to be measured include particulate matter PM, NOx, CO, SO_2, and total hydrocarbons (THC). The test procedures for these pollutants will follow ISO standard 8178, which is extremely similar to the steady-state diesel testing procedures defined by the U.S. EPA and the California ARB. Ammonia (NH_3) and nitrous oxide (N_2O) will be measured only at the inlet and outlet of the emission control system, generally following the procedures specified in EPA Method 320.

2. LOCOMOTIVES TO BE TESTED

The locomotives to be tested are a Electromotive Division (EMD) GP 38 and a General Electric B39-8 or C39-8. The GP 38 is used primarily for switching and local service. It is equipped with a two-stroke, Roots-blown, EMD 16-645E engine. The engine has 16 cylinders and is rated at 2000 tractive horsepower. It has two exhaust stacks, fed by the front eight and rear eight cylinders, respectively. The maximum exhaust flow rate at full power approximately is 6,000 scfm.

The GE Dash-8 series locomotives are used primarily for line-haul freight service, and are equipped with four-stroke, turbocharged, GE FDL-16 engines. These 16-cylinder engines produce 3900 tractive horsepower, and discharge exhaust through a single rectangular stack connected directly to the turbocharger outlet. The maximum exhaust flow rate at full power is approximately 12,000 scfm.

The Union Pacific Railroad will be responsible for supplying the two locomotives for the test, and for ensuring that they are continuously available during the scheduled test period. Both locomotives will need to be available and have full tanks of fuel on July 21. The GE locomotive will then be needed from July 31 to August 5 for testing, and the GP 38 from August 7 to 11.

3. TEST FUEL

The test fuel for the GP 38 will be an ultra-low sulfur diesel fuel meeting ARB regulations for sulfur and aromatic content, as specified in 13 CC 2281 and 2282. The sulfur limit is 15 parts per million w/w, and the limit on aromatic content is 10% v/v unless the fuel is produced according to an approved alternative formulation. The test fuel for the Dash-8 will be a diesel fuel that is actually supplied to Union Pacific line-haul locomotives outside California, and that has a sulfur content between 200 and 500 ppm w/w.

The Union Pacific Railroad will be responsible for ensuring that the locomotives' tanks contain an adequate volume of the appropriate fuel: 3000 gallons for the Dash-8 and 2500 gallons for the GP 38 (this is double the estimated fuel consumption in the test program).

Table 1 shows the analyses to be performed on each fuel sample. EF&EE will collect fuel samples from each locomotive's fuel tank in time for the analyses to take place before the start of emission testing. The fuel tanks will then be sealed and labeled to ensure that fuel is not added to the tanks by mistake.

Table 1: Fuel analyses

ASTM Method	Description
D 2622-94	Sulfur content
D 5291	Carbon-hydrogen-nitrogen elemental content

4. TESTING SCHEDULE

The emission testing calendar is shown in Table 2. Fuel sampling will take place on July 21 to ensure that the results are available before the emission test equipment is installed on July 31. Steady-state emission testing on the Dash 8 will take place August 1 and August 3 to 4, to accommodate the media day scheduled for August 2. These tests will be conducted with the locomotive stationary, and the engine loaded using the "self test" capability of the dynamic brake system.

The test sequence for each day of stationary testing is shown in Table 3. The sequence provides for preconditioning the locomotive engine, and then measuring at idle, Notch 5, and Notch 8. The effects of "souping" (PM buildup in the exhaust system at light loads) will be determined by operating at Notch 3 for half-hour periods following each of the four-hour test periods at idle. The daily test sequence is 10 hours long.

Moving tests, with the locomotive moving back and forth within a restricted section of track, will be conducted on the day following the stationary tests. The schedule for these days is shown in Table 4. Three tests will be conducted, each one-half hour long. The limited length of these tests is based on considerations of operator fatigue, since the engineer will be constantly changing the throttle and reverser positions to move the locomotive back and forth on the 50 foot test section.

Table 2: Emission testing calendar

Date	Activity
July 21	Sample fuel on both locomotives
	Weekend
July 31	Set up emission test equipment for Dash-8
August 1	Stationary test Dash-8
2	Media day
3	Stationary test Dash-8
4	Stationary test Dash-8
5	Moving test Dash-8, remove emission test equipment
	Sunday
August 7	Set up emission test equipment for GP38
8	Stationary test GP38
9	Stationary test GP38
10	Stationary test GP38
11	Moving test GP38, remove emission test equipment

Table 3: Sequence of test modes and testing schedule for stationary test days

Step	Purpose	Throttle	Hours	Cumul. Hours	Test Activity
1	Precondition	3	0.5	0.5	Install filters/check instruments/calibrate
2	Souping baseline	3	0.5	1.0	Measure emissions
3	Stabilize	1	0.5	1.5	Change filters/calibrate
4	Idle Test	1	4.0	5.5	Measure emissions
5	Filter Change	1	0.5	6.0	Change filters/calibrate
6	Souping test	3	0.5	6.5	Measure emissions
7	Stabilize	5	0.5	7.0	Change filters/calibrate
8	Notch 5 Test	5	1.0	8.0	Measure emissions
9	Stabilize	8	0.5	8.5	Change filters/calibrate/refill day tank
10	Notch 8 Test	8	1.0	9.5	Measure emissions and noise
11	Cool down	Idle	0.5	10.0	Remove filters/refill day tank

Table 4: Sequence of test modes and testing schedule for moving test days

Step	Purpose	Throttle	Hours	Cumul. Hours	Test Activity
1	Precondition	3	0.5	0.5	Check/warmup instruments
2	Stabilize	Idle	0.5	1.0	Install filters/calibrate
3	Moving Test #1	Var	0.5	1.5	Measure emissions
4	Filter Change	Idle	0.5	2.0	Change filters/calibrate
5	Moving Test #2	Var	0.5	2.5	Measure emissions
6	Filter Change	Idle	0.5	3.0	Change filters/calibrate
7	Moving Test #3	Var	0.5	3.5	Measure emissions
8	Change locomotive	Off	2.0	5.5	Remove RAVEM

Five emission tests will be conducted during each of the three days of stationary testing on each locomotive, and three during the one day of moving tests. Thus, a total of 18 emission tests will be conducted on each locomotive.

5. PARTICULATE EMISSION MEASUREMENTS

PM emissions before and after the ALECS system will be measured according to the isokinetic partial flow dilution method specified as one option under ISO 8178. Raw exhaust will be extracted from the exhaust conduit using EF&EE's RAVEM isokinetic sampling system. In the RAVEM system, isokinetic sampling conditions are maintained by adjusting the flow rate of raw exhaust through the sample probe until the static pressures inside and outside the probe are equal. This adjustment is performed continuously in real time by the RAVEM system, allowing it to follow transient changes in exhaust flow rate.

The raw exhaust from the sample probe will pass through a 250 ^{o}C heated sample line to the RAVEM dilution tunnel. Dilution air will pass through a prefilter and a HEPA filter before entering the tunnel. Dilute exhaust containing PM will be drawn from the dilution tunnel through a PM10 cyclone (URG 2000-30ENB), and then through filters of Teflon film or Teflon coated borosilicate glass in accordance with ISO 8178 and 40 CFR 1065. The rate of exhaust extraction will be controlled to a constant value of 16.7 standard liters per minute by a mass flow controller (Alicat MC 50 slpm) using the laminar flow principle. The dilution flow rate in the CVS will be adjusted to ensure that the gas temperature at the filter face is no more than 52 ^{o}C. Blank filters exposed only to dilution air will be collected along with each sample. In addition to correcting for any background PM that makes it past the HEPA filter, subtracting the change in weight of the blank filter from the sample weight also automatically corrects for the effects of small differences in weighing chamber temperature, humidity, and atmospheric pressure.

ISO 8178 specifies the use of both primary and backup filters for each sample, while 40 CFR 1065 specifies the use of a single filter mounted in a filter cassette. Up to this point, EF&EE has used the ISO 8178 method, but the 40 CFR 1065 method appears advantageous in reducing the risk of filter damage during handling. During May, 2006, EF&EE will experiment with the Part 1065 method, and will recommend one or the other approach to the testing committee.

Separate RAVEM samplers will be used to sample the exhaust at the locomotive stack, at the inlet to the ALECS system, and in the outlet stack from the ALECS system. A total of 6 PM samples will be collected for each of the 36 emission tests – three PM samples and three blanks. Thus, a total of 216 pre-weighed filter cassettes (or pairs of pre-weighed filters, if the Committee opts to retain primary and backup filters) will be required.

At the request of the ARB Monitoring and Laboratory Division, the RAVEM sampler at the ALECS system inlet will be modified to allow a second PM sampler to be connected. The additional sampler will be provided by ARB, and will be used to collect 47 mm Teflon filters for characterization of the hydrocarbon content of the PM in an effort to identify potential marker chemicals for PM source apportionment.

6. GASEOUS EMISSION MEASUREMENTS

Gaseous emission measurements will include oxides of nitrogen (NOx), total hydrocarbons (THC), carbon monoxide (CO), carbon dioxide (CO_2), sulfur dioxide (SO_2), oxygen (O_2), ammonia (NH_3), and nitrous oxide (N_2O). Table 5 summarizes the gas concentration measurement techniques to be used. Except for the FTIR measurements, all of the analyzers and measurement techniques will comply with ISO 8178 specifications.

The ALECS system itself includes continuous emission monitoring systems for NOx, SO_2, and O_2 at both the inlet and the outlet, and for THC and NH_3 at the outlet only. These analyzers are configured for raw gas sampling, which means that the results must be combined with a measured exhaust gas flow rate to calculate the total mass of emissions. The exhaust flowrate measurement is provided by venturis located in both the inlet and outlet sections.

Table 5: Gas concentration measurements by sampling location

	Locomotive Stack	**ALECS Inlet**	**ALECS Outlet**
NOx	Dilute**	Raw+/Bag**	Raw+/Bag**
THC		Raw	Raw+
CO	Dilute**	Raw/Bag**	Raw/Bag**
CO2	Dilute**	Raw/Bag**	Raw/Bag**
SO2	-	Raw+	Raw+
NH3	-	FTIR*	FTIR*/CLD+
N2O	-	FTIR*	FTIR*
Gas Flow	-	Venturi+	Venturi+

*Time-shared between inlet and outlet
+ALECS system equipment
**RAVEM system equipment

The RAVEM sampling systems perform exhaust gas dilution according to the constant volume sampling (CVS) principle, so that the pollutant concentration in the dilute gas is proportional to the pollutant mass flow rate in the exhaust. The RAVEM system located at the locomotive stack will be configured to measure dilute NOx, CO, and CO_2 continuously, as well as collecting integrated bag samples of the dilute gas to be analyzed after the end of each test. The RAVEM samplers at the ALECS inlet and outlet will collect integrated bag samples only, to be analyzed at the end of each test by the analyzers of the first RAVEM system. The results will be used to calculate a carbon balance check for the PM sampling. The dilute NOx results from these bags will also be available as a backup to NOx measurements of the ALECS CEMS systems.

The ALECS system includes an analyzer to measure ammonia emissions by oxidizing the ammonia to NOx, measuring NOx by CLD, and subtracting the NOx already present in the sample gas (determined by another CLD analyzer). The accuracy of this method potentially suffers from the difference-of-large-numbers problem. A more accurate measurement of ammonia emissions, as well as N_2O, can be obtained by Fourier Transform Infrared (FTIR) analysis. EF&EE will apply its MIDAC FTIR analyzer system to measure NH_3 and N_2O concentrations in the raw gas at both the ALECS inlet and outlet. Heated sample lines will bring gas samples from each source to a heated valve/filter combination next to the FTIR unit. The system will measure emissions primarily from the ALECS outlet, but will be switched to measure inlet emissions several times during each steady-state test.

Prior to beginning the emission testing, 10-point linearity checks will be performed on all gas analyzers using EF&EE's Environics 4000-series precision dilution system. The FTIR system will be checked using the diesel exhaust procedure specified in the Water Transit Authority testing protocol. Zero and span calibrations will be performed on each gas analyzer after each emission test.

7. FUEL CONSUMPTION MEASUREMENTS

Fuel consumption will be measured during each emission test as a check on the accuracy of the emission measurements. If these measurements are accurate, the sum of the carbon contained in the CO_2, CO, HC, and PM emissions should be equal to the mass of carbon in the fuel consumed.

Fuel consumption by the locomotive engine will be measured using a 250 gallon "tote" positioned on a pallet scale as a day tank. EF&EE staff will install three-way valves in the locomotive's fuel supply and return lines to allow these to be switched between the locomotive fuel tank and the day tank. Switching both supply and return lines to the day tank will mean that the change in weight of the day tank is equal to the fuel consumed by the engine. The day tank will be filled (and refilled, when necessary) from the locomotive fuel tank by running the electric fuel pump with the supply line connected to the locomotive tank, and the return line connected to the day tank.

Since locomotive fuel systems can contain voids and air pockets that affect the fuel balance during startup, the system will be stabilized while running on the day tank before beginning each emission test. The weight of fuel in the day tank will be recorded at frequent intervals automatically during the test.

Since the returned fuel picks up considerable heat in the engine, it will be necessary to cool it before returning it to the day tank. Otherwise, the relatively small volume of fuel in the day tank could become hot enough to affect the emissions results (hotter fuel is less viscous, atomizes and ignites more readily). Cooling will be achieved by running it through a fuel-to-air heat exchanger.

8. NOISE MEASUREMENTS

Locomotive noise measurements will be performed using a hand-held noise meter. Emission measurements will be made using the "slow" response function of the meter, at a point 30 meters away from the locomotive along a line passing through the center of the locomotive perpendicular to the track, and will follow the requirements of 40 CFR 201.20 et seq. as closely as possible, given the conditions of the test site. Notch 8 noise measurements will be made within 15 minutes of the end of the test. Background noise measurements will be made in the same location as soon as possible after the locomotive engine has cooled down from Notch 8 operation and been turned off.

Baseline noise tests at Notch 8 will be made once the locomotive is in place on the test track, but prior to attaching the locomotive exhaust to the ALECS system. The baseline noise test will be repeated at the end of testing, after disconnecting the locomotive from the ALECS system and before moving it from the test track.

9. USE OF WATER, ELECTRICITY, AND CONSUMABLES

9.1 Solid waste characterization

The solid waste (sludge) is collected in filter bags at two locations in the ALECS system: at the discharge of the Preconditioning Chamber (PCC), and at the discharge of the Cloud Chamber Scrubber (CCS). Total PM mass will be determined by weighing the bags after use. The variation in bag weight is negligible in comparison to the weight of particulate each will collect, so an average bag weight will be used for the "before" weight. The bags will be hung to dry before weighing in order to allow water retained in the bag fabric to evaporate.

Filter bags will be changed between tests for the two locomotives.

Samples of the collected sludge will be taken and sent to an outside lab for the following analyses:

- Oil & grease (Refer to EPA Method 413.1)
- Heat content (Btu content)
- ICP (Inductively Coupled Plasma) tests for metals such as Cu, Ni, Pb, Cr, and Zn (Refer to EPA Method 200.7)
- IC (Ion Chromatography) tests for anions such as Cl, F, NO2, NO3, and SO4 (Refer to EPA Method 300.0)
- TPH (Total Petroleum Hydrocarbons) (Refer to EPA Method 418.1)

9.2 Wastewater (blowdown) characterization

Rotometers will be adjusted to set the blowdown for the PCC and the CCS. These rates will be set to maintain the conductivity within specified limits. The blowdown rate will be a function of the sulfur content in the exhaust gas stream, and will be experimentally determined. The total blowdown for any period of time will be determined by measuring the level in the wastewater tank.

Properties of the water in the recirculation loops will be monitored as part of the control system, and will be used in part to determine the blowdown. These properties are:

- pH
- conductivity

Samples of wastewater will be collected for analysis prior to starting the test, at the changeover from the Dash 8 to the GP 38, at the end of the test, and periodically as deemed necessary during the test program. The analysis will include:

- suspended solids (Refer to EPA Method 160.2)
- dissolved solids (Refer to EPA Method 160.1)
- pH (Refer to EPA Method 150.1)
- conductivity (Refer to EPA Method 120.1)
- IC anions (Refer to EPA Method 300.0)
- ICP metals (Refer to EPA Method 200.7)
- Oil & grease (Refer to EPA Method 413.1)

9.3 Water usage

The inlet water flow rate will be intermittent. When the need for makeup water is detected by sensors in the system, a solenoid valve will be opened for a fixed, preset length of time to admit water to the system. The flow rate during the time the valve is open will be determined one time by physically measuring the amount of water that flows during one valve-open period. The control system will log the number of valve openings during system operation, and from these two quantities the total inlet water will be determined.

9.4 Electricity Use

Electricity use will be the sum of two parts as far as measurement is concerned. There is a base load, which is the usage for basic system functions such as instrumentation and controls, and a variable load, which is the power consumption of the various motors that drive pumps and fans.

The base load will be measured with a clamp-on meter. This will be an essentially constant quantity.

By far the majority of the power used is consumed by the pump and fan motors. These are all driven by variable frequency drives controlled by the control system, and the power consumption of each individual motor is logged by the control system. These are real time, continuous measurements and will form part of the output data. The sum of these motor powers and the base power will give the total power consumption.

9.5 Urea Consumption

The urea is introduced into the exhaust gas stream by three separate injection lances. Each lance has its own metering pump and flow transmitter. These flow data will be logged by the control system.

9.6 NaOH Consumption

Sodium hydroxide is fed into the system by constant volume pumps that are either on or off, and the feed will be controlled by the pH of the recirculating water. These pumps will initially be adjusted so that they will be running 60% to 80% of the time with the maximum expected sulfur load in the exhaust gas.

Following this initial adjustment, the pumps will either be on or off. The flow rate during the on state will be determined by a physical measurement of volume over a given time. This will give us the flow rate in gallons per minute of on-time.

The control system will log the on-time, both instantaneous and cumulative, and this will be used to determine the total NaOH usage.

Appendix B. EF&EE Emission Test Report

ENGINE, FUEL, AND EMISSIONS ENGINEERING, INCORPORATED

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March 27, 2007

Don Duffy
Placer County Air Pollution Control District
3091 County Center Drive, Suite 240
Auburn, CA 95603

Dear Don:

As you requested, this letter responds to two of the comments by the Union Pacific Railroad on our report, Emission Measurements on the Advanced Locomotive Emissions Control System at the J.R. Davis Rail Yard . These were received too late to be addressed in the final report.

One comment concerned the recommendation in the Executive Summary that "… locomotives should first be operated at higher load with the ALECS system in place after a prolonged period of idle or Notch 1 operation." Union Pacific commented that "The comment about the use of the ALECS following prolonged idle should be deleted, as it is not accompanied by an analysis of whether such an operating mode is practical, or what the emissions might be associated with moving a locomotive from another portion of the railyard to the location where the ALECS might be installed. At page 19, this recommendation is framed as continuing to leave the locomotive connected to the ALECS for a few minutes after a prolonged idle, and not as connecting a locomotive to ALECS after a prolonged idle."

We disagree with this comment. The sentence in the Executive Summary simply summarizes the recommendation on Page 19. Nothing in our report should be read as recommending that locomotives be moved from another location to the ALECS system *after* a prolonged idling period. Instead, our understanding of the potential use of the ALECS system is that locomotives would be moved to it and connected prior to *beginning* a prolonged period of idle.

In another comment, Union Pacific requested that we note that no emission tests were performed at idle, and that all references to idle in our report should be changed to Notch 1. This is correct. Although it was originally planned that testing would be carried out at idle, concerns about the minimum design exhaust flow rate for the ALECs system led to the test condition being changed to Notch 1. In several places in the final report, it is stated incorrectly that the test locomotive was operating at idle. All such references should be read as referring to "Notch 1" instead.

I hope that this will clarify any confusion on these issues.

Christopher S. Weaver, P.E.
President

EMISSION MEASUREMENTS ON THE ADVANCED LOCOMOTIVE EMISSION CONTROL SYSTEM AT THE J.R. DAVIS RAIL YARD

FINAL REPORT

February 26, 2007

submitted to:
Technology Advancement Office
South Coast Air Quality Management District
and
Placer County Air Pollution Control District

EF & EE
ENGINE, FUEL, AND EMISSIONS ENGINEERING, INCORPORATED

EMISSION MEASUREMENTS ON THE ADVANCED LOCOMOTIVE EMISSION CONTROL SYSTEM AT THE J.R. DAVIS RAIL YARD

Final Report

February 26, 2007

<u>Submitted to</u>
Technology Advancement Office
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Placer County Air Pollution Control District
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EXECUTIVE SUMMARY

The Union Pacific Railroad's J.R. Davis rail yard in Roseville, California, is a major center for locomotive maintenance, as well as for assembling and reassembling trains of freight cars. Locomotive operations at the rail yard have been determined to be a significant source of emissions of diesel particulate matter (PM) and other pollutants. An agreement between the Placer County Air Pollution Control District (APCD) and the Union Pacific Railroad Company includes a mitigation plan for reducing PM emissions from the rail yard. Part of this plan is an assessment of the use of stationary air pollution control equipment to capture and treat emissions from stationary locomotives while idling or undergoing engine load tests.

The Advanced Locomotive Emission Control System (ALECS) comprises a set of stationary emissions control equipment connected to an articulated bonnet or hood. The hood is designed to capture locomotive exhaust, delivering it to the ground-mounted emission control system by means of a flexible duct. The hood remains attached while the locomotive is moving along the track to the extent of the flexible duct. The emission control equipment comprises a sodium hydroxide wash to remove sulfur dioxide (SO_2), a triple cloud chamber scrubber for particulate matter (PM) removal, and a Selective Catalytic Reduction (SCR) reactor to reduce oxides of nitrogen (NOx). The demonstration ALECS is designed to treat exhaust flows between 2,000 and 12,000 standard cubic feet per minute (scfm). The former is slightly more than the exhaust flow from a locomotive at idle, while the latter is approximately the exhaust flow from a line-haul locomotive at Notch 8 (full power).

The ALECS demonstration is a public-private collaborative project involving the Placer County APCD, U.S. Environmental Protection Agency, Sacramento Metropolitan Air Quality Management District, Union Pacific Railroad, Advanced Cleanup Technologies Inc., the South Coast Air Quality Management District (SCAQMD), the California Air Resources Board, and the City of Roseville. Engine, Fuel, and Emissions Engineering, Inc. (EF&EE) was contracted by the SCAQMD to carry out emission measurements before and after the ALECS system.

Emission measurements were performed on two locomotives: an EMD GP38 and a General Electric C39-8 (Dash 8). The GP38 has a 2000 horsepower two-stroke diesel engine, and is typically used for switching and local service. The Dash-8 has a 3900 horsepower four-stroke engine, and is normally used for line-haul freight service. Tests were performed with the locomotives stationary at idle, Notch 3, Notch 5, and Notch 8 power settings, and while moving slowly in Notch 1.

Measurements before and after the ALECS system showed NOx removal efficiency of 96 to 100%, with efficiency of 99% or more in most test modes. SO_2 emissions were low to begin with, were further reduced by 85 to 100%. PM control efficiency ranged from 89 to 99% over most test modes, but was only 81% in Notch 5 operation on the Dash 8. This mode had a high exhaust flow rate with low PM concentration.

CO_2 emissions increased through the ALECS system, as a result of the fuel-fired reheat stage before the SCR reactor. CO emissions were very low to begin with, but increased somewhat

through the system. Emissions due to ammonia slip from the SCR system ranged from zero (in most operating modes) to 1.3 grams per minute in full-power operation on the Dash 8. The latter emission rate was about 1/700th of the mass of NOx emissions destroyed by the ALECS system.

Testing conducted before and after prolonged periods of Notch 1 operation showed that PM buildup or "souping" during Notch 1 accounted for 26 to 37% of the total emissions attributable to Notch 1 operation. Although produced in Notch 1, this material adheres to the exhaust system, and is emitted subsequently, when the locomotive returns to higher-power operation. The ALECS system was virtually 100% effective in controlling the PM spikes due to this buildup. This suggests that the locomotives should first be operated at higher load with the ALECS system in place after a prolonged period of idle or Notch 1 operation.

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1. INTRODUCTION

The Union Pacific Railroad's J.R. Davis rail yard in Roseville, California, is a major center for locomotive maintenance, as well as for assembling and reassembling trains of freight cars. Locomotive operations at the rail yard have been determined to be a significant source of emissions of diesel particulate matter (PM) and other pollutants.[1] An agreement between the Placer County Air Pollution Control District (APCD) and the Union Pacific Railroad Company includes a mitigation plan for reducing PM emissions from the rail yard. This plan includes considering the use of stationary air pollution control equipment to capture and treat emissions from stationary locomotives while idling or undergoing engine load tests. To carry out this part of the plan, the APCD initiated a project to demonstrate the Advanced Locomotive Emission Control System (ALECS).

The ALECS demonstration is a public-private collaborative project involving many parties. Participants include the APCD, U.S. Environmental Protection Agency, Sacramento Metropolitan Air Quality Management District, Union Pacific Railroad, Advanced Cleanup Technologies Inc., the South Coast Air Quality Management District (SCAQMD), the California Air Resources Board, and the City of Roseville. Engine, Fuel, and Emissions Engineering, Inc. (EF&EE) was tasked with carrying out the emissions measurements under a contract with the SCAQMD.

1.1 Overview of the ALECS

The ALECS is designed to control harmful emissions from locomotives by capturing the exhaust stream from their engines and treating it to remove most pollutants. The system includes a set of stationary emissions control equipment connected to an articulated bonnet or hood. The hood is designed to capture locomotive exhaust, delivering it to the ground-mounted emission control system by means of a flexible duct. The bonnet or hood remains attached while the locomotive is moving along the track to the extent of the flexible duct.

The ALECS's emissions control equipment comprises a sodium hydroxide wash to remove sulfur dioxide (SO_2), followed by a triple cloud chamber scrubber for particulate matter (PM) removal. The exhaust is then reheated and passed through a Selective Catalytic Reduction (SCR) reactor to reduce oxides of nitrogen (NOx). The SCR reactor uses urea as the ammonia source. The demonstration ALECS is designed to treat exhaust flows between 2,000 and 12,000 standard cubic feet per minute (scfm).

1.2 Objectives

The objectives of the test program were:

- To measure and document the effectiveness of the ALECS system in controlling locomotive emissions of diesel particulate matter (PM), oxides of nitrogen (NOx) and other pollutants of concern under typical railyard operating conditions;

- To assure that the emission control process does not generate excessive amounts of other pollutants, such as ammonia;

- To quantify the effect of the hood system on locomotive noise emissions at full power; and
- To quantify the water and chemical consumption, operating costs, and waste generated by the ALECS system. (This information was compiled by ACTI during the test program, and is outside the scope of the present report).

2. THE TEST PROGRAM

The test program included emission measurements at three locations: at the inlet to the ground-mounted emission control system, at the outlet from the emission control system**,** and in the locomotive stack(s). The effectiveness of the ALECS emission control system was determined by comparing the mass emissions measured at the inlet with those measured at the system outlet. Emission measurements at the locomotive stack were obtained to make it possible to identify any effects on pollutant mass or characteristics due to the overhead manifold system.

The test program included two locomotives, each of which was operated in a defined set of test modes. Each of the test modes was repeated at least three times. Pollutants measured included PM, NOx, CO, SO_2, and total hydrocarbons (THC). The test procedures for these pollutants followed ISO standard 8178, which is extremely similar to the steady-state diesel testing procedures defined by the U.S. EPA and the California ARB. Ammonia (NH_3) and nitrous oxide (N_2O) were measured at the inlet and outlet of the emission control system during some of the tests, generally following the procedures specified in EPA Method 320.

2.1 Test Locomotives

The two locomotives tested were made available by the Union Pacific Railroad. They were a General Electric (GE) C39-8 line-haul locomotive (UPRR 9143) and an Electromotive Division (EMD) GP38 road-switcher (UPRR 604). The GE Dash-8 series locomotives are used primarily for line-haul freight service, and are equipped with four-stroke, turbocharged, GE FDL-16 engines. These 16-cylinder engines produce 3900 tractive horsepower, and discharge exhaust through a single rectangular stack connected directly to the turbocharger outlet. The maximum exhaust flow rate at full power is approximately 12,000 scfm.

The GP38 is used primarily for switching and local service. It is equipped with a two-stroke, Roots-blown, EMD 16-645E engine. The engine has 16 cylinders and is rated at 2000 tractive horsepower. It has two exhaust stacks, fed by the front eight and rear eight cylinders, respectively. The maximum exhaust flow rate at full power approximately is 6,000 scfm.

2.2 Test Fuel

The test fuel for the GP38 was ultra-low sulfur diesel fuel meeting ARB regulations for sulfur and aromatic content, as specified in 13 CC 2281 and 2282. The sulfur limit is 15 parts per million w/w, and the limit on aromatic content is 10% v/v unless the fuel is produced according to an approved alternative formulation. The test fuel for the Dash-8 was a diesel fuel that is actually supplied to Union Pacific line-haul locomotives outside California. This fuel was specified with a sulfur content between 200 and 500 ppm w/w.

Table 1 shows the results of analyses performed on each fuel sample. EF&EE collected fuel samples from each locomotive's fuel tank during the test program. The fuel tanks were sealed and labeled to ensure that fuel was not added to the tanks by mistake.

Table 1: Fuel analyses

	Method	Dash 8	GP38
Carbon Content	D-5291	86.00%	86.10%
Hydrogen Content	D-5291	13.33%	13.73%
Nitrogen Content	D-5291	0.50%	0.06%
Sulfur Content (ppm)	D-4294	500	<15

2.3 TESTING SCHEDULE

The test sequence originally planned for each day of stationary testing is shown in Table 2. The sequence was designed to provide for preconditioning the locomotive engine, and then for measuring at Notch 1, Notch 5, and Notch 8. The effects of "souping" (PM buildup in the exhaust system at light loads) were determined by operating at Notch 3 for half-hour periods following each of the test periods at Notch 1, and comparing the results to a baseline measurement made at Notch 3 following a half hour of preconditioning at Notch 3.

Because of equipment problems and other issues, the actual test program diverged considerably from the sequence shown in Table 2. However, each test mode except the "Souping" tests was always preceded by at least 30 minutes of operation at the same mode to stabilize engine temperature. Notch 1 tests were also preceded by at least 30 minutes at Notch 3 to eliminate any "soup" buildup before the start of the test. The "Souping" test always followed a substantial period of operation at idle, generally comprising a Notch 1 test, the preceding stabilization period, and the time required for changing filters and reading sample bags at the end of the test.

The original schedule called for each Notch 1 test to be four hours long, and each test at Notches 5 and 8 to be one hour. This was based on considerations of the minimum detectable PM emission level at the outlet, assuming 99% collection efficiency by the ALECS. Based on the PM buildup observed on the filters during the first few tests, however, it was concluded that the length of the Notch 1 and Notch 8 tests could be cut in half.

Moving tests were conducted with the locomotive moving back and forth within a restricted section of track. The schedule for these days is shown in Table 3. Three tests were conducted, each one-half hour long. The limited length of these tests is based on considerations of operator fatigue, since the engineer will be constantly changing the throttle and reverser positions to move the locomotive back and forth on the 50 foot test section.

Table 2: Planned sequence of test modes and testing schedule for stationary test days

Step	Purpose	Throttle	Hours	Cumul. Hours	Test Activity
1	Precondition	3	0.5	0.5	Install filters/check instruments/calibrate
2	Souping baseline	3	0.5	1.0	Measure emissions
3	Stabilize	1	0.5	1.5	Change filters/calibrate
4	Idle test	1	4.0	5.5	Measure emissions
5	Filter Change	1	0.5	6.0	Change filters/calibrate
6	Souping test	3	0.5	6.5	Measure emissions
7	Stabilize	5	0.5	7.0	Change filters/calibrate
8	Notch 5 test	5	1.0	8.0	Measure emissions
9	Stabilize	8	0.5	8.5	Change filters/calibrate/refill day tank
10	Notch 8 test	8	1.0	9.5	Measure emissions and noise
11	Notch 8 noise baseline	8	.1	9.6	Raise bonnet and re-measure noise
12	Cool down	Idle	0.4	10.0	Remove filters/refill day tank

Table 3: Planned sequence of test modes and testing schedule for moving test days

Step	Purpose	Throttle	Hours	Cumul. Hours	Test Activity
1	Precondition	3	0.5	0.5	Check/warmup instruments
2	Stabilize	Idle	0.5	1.0	Install filters/calibrate
3	Moving Test #1	Var	0.5	1.5	Measure emissions
4	Filter Change	Idle	0.5	2.0	Change filters/calibrate
5	Moving Test #2	Var	0.5	2.5	Measure emissions
6	Filter Change	Idle	0.5	3.0	Change filters/calibrate
7	Moving Test #3	Var	0.5	3.5	Measure emissions
8	Change locomotive	Off	2.0	5.5	Remove RAVEM

2.4 PARTICULATE EMISSION MEASUREMENTS

PM emissions before and after the ALECS system were measured using EF&EE’s Ride-Along Vehicle Emissions Measurement (RAVEM) system. The RAVEM uses the isokinetic partial flow dilution method specified as one option under ISO 8178. Raw exhaust is extracted from the exhaust conduit using an isokinetic sampling system. Isokinetic sampling conditions are maintained by adjusting the flow rate of raw exhaust through the sample probe until the static pressures inside and outside the probe are equal. This adjustment is performed continuously in real time by the RAVEM system, allowing it to follow transient changes in exhaust flow rate.

The raw exhaust from the sample probe was passed through an insulated sample line to the RAVEM dilution tunnel. Dilution air passed through a prefilter and a HEPA filter before entering the tunnel. Dilute exhaust containing PM was then drawn from the dilution tunnel through a PM2.5 cyclone (URG 2000-30EH), and then through filters of Teflon film in accordance with ISO 8178 and 40 CFR 1065. The rate of exhaust extraction was controlled to constant values of 16.7 standard liters per minute (SLPM) for the RAVEM systems measuring outlet and stack emissions, and 10 SLPM for the inlet RAVEM. The dilution flow rate in the

CVS was adjusted to ensure that the gas temperature at the filter face was no more than 52 ^oC. Blank filters exposed only to dilution air were collected along with each sample. In addition to correcting for any background PM that makes it past the HEPA filter, subtracting the change in weight of the blank filter from the sample weight also automatically corrects for the effects of small differences in weighing chamber temperature, humidity, and atmospheric pressure.

ISO 8178 specifies the use of both primary and backup filters for each sample, while 40 CFR 1065 specifies the use of a single filter mounted in a filter cassette. For compatibility with the ongoing ambient sampling program at the railyard, EF&EE used the 40 CFR 1065 method during these tests.

Separate RAVEM samplers were used to sample the exhaust at the locomotive stack, at the inlet to the ALECS system, and in the outlet stack from the ALECS system. One Teflon sample filter and one Teflon blank were collected by each RAVEM during each test. In addition, the RAVEM system at the ALECS inlet collected one sample and one dilution air blank on 47 mm quartz filters during each test. These filters are to undergo analysis for elemental vs. organic carbon (EC/OC) content by the South Coast AQMD.

Figure 1: RAVEM installations at the ALECS inlet and outlet

At the request of the ARB Monitoring and Laboratory Division, the RAVEM sampler at the ALECS system inlet was also modified to allow a third PM sampler to be connected. The additional sampler was provided by ARB, and was used without a cyclone to collect 47 mm Teflon filters. These will be analyzed by ARB for mass and characterization of the hydrocarbon content of the PM in an effort to identify potential marker chemicals for PM source apportionment.

2.5 GASEOUS EMISSION MEASUREMENTS

Gaseous emission measurements included oxides of nitrogen (NOx), total hydrocarbons (THC), carbon monoxide (CO), carbon dioxide (CO_2), sulfur dioxide (SO_2), oxygen (O_2), ammonia (NH_3), and nitrous oxide (N_2O). Table 4 summarizes the gas concentration measurement techniques used. Except for the FTIR measurements, all of the analyzers and measurement techniques complied with ISO 8178 specifications.

The ALECS system itself includes continuous emission monitoring systems (CEMS) for NOx, SO_2, and O_2 at both the inlet and the outlet, and for THC and NH_3 at the outlet only. For these tests, EF&EE provided another THC analyzer for the inlet. The CEMS analyzers are configured for raw gas sampling, which means that the results must be combined with a measured exhaust gas flow rate to calculate the total mass of emissions. The exhaust flowrate measurement is provided by venturis located in both the inlet and outlet sections.

THC emissions in the CEMS are measured “hot” and “wet” – directly from a heated line maintained at 190 +/- 10 C. The other pollutants are measured “dry” -- after moisture is removed by a sample conditioning system. The NH_3 measurement method used by the ALECS is that specified in ISO 8178 – conversion of NH_3 to NO, followed by quantification using a chemilumenescent analyzer. Since NH_3 is highly soluble in water, it was converted to NO prior to the sample conditioning step.

Table 4: Gas concentration measurements by sampling location

	Locomotive Stack	**ALECS Inlet**	**ALECS Outlet**
NOx	Dilute**	Raw+/Bag**	Raw+/Bag**
THC		Raw	Raw+
CO	Dilute**	Raw/Bag**	Raw/Bag**
CO_2	Dilute**	Raw/Bag**	Raw/Bag**
SO_2	-	Raw+	Raw+
NH_3	-	FTIR*	FTIR*/CLD++
N_2O	-	FTIR*	FTIR*
Gas Flow	-	Venturi+	Venturi+

*Fourier Transform Infrared of raw gas, time-shared between inlet and outlet
+ALECS system equipment **RAVEM system equipment
++ALECS system ammonia-to-NO with chemilumenescent detector

The effect of removing water vapor on pollutant concentrations in the remaining gas is substantial, especially in the outlet from the ALECS system. The water vapor concentration in the inlet gas was calculated from the absolute humidity of the ambient air and the chemical composition of the fuel. For the outlet gas, the water vapor concentration is determined by the exit conditions from the cloud chambers. According to the supplier, Tri-Met Corporation, these conditions were 140 to 150 ^oF and 95% relative humidity. For the emission calculations, we assumed 24.7% by volume of water vapor in the outlet gas, corresponding to conditions of 145 ^oF and 95% humidity.

The RAVEM sampling systems perform exhaust gas dilution according to the constant volume sampling (CVS) principle, so that the pollutant concentration in the dilute gas is proportional to the pollutant mass flow rate in the exhaust. The RAVEM system located at the ALECS inlet was configured to measure dilute NOx, CO, and CO_2 continuously, as well as collecting integrated bag samples of the dilute gas to be analyzed after the end of each test. The RAVEM samplers at the outlet and at the locomotive stack collected integrated bag samples only. These were analyzed at the end of each test by the analyzers of the first RAVEM system.

The results of the CO_2 measurements were used to calculate a carbon balance check for the PM sampling. The dilute NOx results from these bags were also compared to the NOx measurements of the ALECS CEMS systems.

The ALECS system ammonia analyzer works by oxidizing the ammonia to NO, measuring NO by CLD, and subtracting the NO already present in the sample gas (determined by another CLD analyzer). The accuracy of this method potentially suffers from the difference-of-large-numbers problem. A more accurate measurement of ammonia emissions, as well as N_2O, can be obtained by Fourier Transform Infrared (FTIR) analysis. During several emission tests, EF&EE applied a MIDAC FTIR analyzer system to measure NH_3 and N_2O concentrations in the raw gas at both the ALECS inlet and outlet. A heated sample line was used to bring gas samples from each source to a heated filter next to the FTIR unit.

2.6 Fuel Consumption Measurements

Fuel consumption was measured during each stationary emission test as a check on the accuracy of the results. If the measurements are accurate, the sum of the carbon contained in the CO_2, CO, HC, and PM emissions should be equal to the mass of carbon in the fuel consumed.

Fuel consumption by the locomotive engine was measured using a 250 gallon intermediate bulk container positioned on a pallet scale as a day tank, as shown in Figure 2. Three-way valves were installed in the locomotive's fuel supply and return lines to allow these to be switched between the locomotive fuel tank and the day tank. Switching both supply and return lines to the day tank meant that the change in weight of the day tank was equal to the fuel consumed by the engine. The day tank was filled (and refilled, when necessary) from the locomotive fuel tank by running the electric fuel pump with the supply line connected to the locomotive tank, and the return line connected to the day tank.

Since locomotive fuel systems can contain voids and air pockets that affect the fuel balance during startup, the system was stabilized while running on the day tank before beginning each emission test. The weight of fuel in the day tank was recorded at 1-second intervals automatically during the test.

Although the returned fuel can pick up considerable heat in the engine, the relatively large volume of fuel in the day tank and the length of the supply and return hoses made it unnecessary to cool the fuel during these tests.

Figure 2: Dash 8 locomotive under emission testing, showing the fuel day tank

3. EMISSION RESULTS

This program employed three different approaches to emission measurements: the RAVEM partial-flow dilution systems, the ALECS's own CEMS systems using conventional analyzers, and FTIR analysis of the raw exhaust for ammonia and N_2O. The RAVEM results are presented and discussed in Section 3.1, the CEMS results in Section 3.2, and the FTIR results in Section 3.3. The effects of "souping" – the buldup of PM in the exhaust system at light loads, to be emitted later when the exhaust temperature increases – are quantified in Section 3.4. Section 3.5, finally, compares the limited RAVEM measurements conducted in the locomotive exhaust stacks with those at the inlet to the ALECS system.

3.1 RAVEM RESULTS: PM, NOX, CO, AND CO_2

RAVEM system measurements from the stationary testing of the Dash 8 locomotive are shown in Table 5. Emissions were measured separately at the inlet and outlet the ALECS system, using two separate RAVEM units. Results (in grams of pollutant per minute) are shown for each test, as well as for the mean and coefficient of variation (standard deviation divided by the mean) in each test mode. Except for the Test 959 (the final souping test), the coefficients of variation are relatively low, and within expectations for test-to-test variability.

The emission control effectiveness of the ALECS system can be calculated from the ratio of the pollutant mass flow at the outlet to that at the inlet. For NOx, the control efficiencies ranged from 96.8% to 100%. For PM, the control efficiency ranged from 97% at low loads to 81% at Notch 5; increasing to 88.8% at Notch 8. CO emissions were extremely low at the inlet, and increased slightly in passing through the system. CO_2 emissions also increased through the ALECS system, due to the use of fuel to reheat the exhaust before the SCR system.

Table 5 also compares the fuel consumption measured by the change in weight of the day tank to that calculated from the emission results by carbon balance. Only the inlet fuel data are shown, as the outlet CO_2 emissions include the fuel used by the exhaust reheater in the ALECS system, and are thus not directly comparable to the measured fuel use. Except at Notch 1, the measured and calculated fuel consumption agree within a few percent, showing that the RAVEM was accurately collecting a proportional sample of the exhaust. The results for Notch 1, however, show that the RAVEM was oversampling by about 50%. The exhaust velocities and flow rates in this condition are extremely low, and the differential pressure signal used by the RAVEM system is proportional to the square of the exhaust velocity. Thus, at very low velocities, any inaccuracy in the sampling system can have a substantial effect. Thus, assuming that the measured fuel consumption data are accurate, the RAVEM results at idle should be multiplied by a factor 0.67 to get the true emissions.

Table 5: ALECS inlet vs. outlet emissions - RAVEM data for the Dash 8

Test No.	Start Date/Time	Inlet Emissions (g/min)				Outlet Emissions (g/min)				Inlet Fuel (g/min)		
		CO_2	CO	NOx	PM	CO_2	CO	NOx	PM	Calc.	Meas.	Ratio
DASH 8 - NOTCH 8												
T0946	9/8/2006 18:29	30,424	122	689	24.6	11,658	40	0.0	1.5	9,642	10,058	96%
T0951	9/10/2006 10:44	31,281	110	647	28.3	36,274	162	22.4	2.9	9,975	10,043	99%
T0952	9/10/2006 12:23	29,197	113	631	26.5	32,697	134	18.4	2.9	9,316	8,543	109%
T0953	9/11/2006 11:23	30,059	120	651	23.0	33,564	143	26.6	2.6	9,592	10,021	96%
T0955	9/11/2006 13:33	30,073	130	624	25.0	32,697	143	14.3	3.0	9,602	9,850	97%
Average		30,207	119	648	25.5	33,808	146	20.4	2.9	9,703	9,993	97%
Coeff. Of Deviation		2.5%	6.5%	3.9%	7.9%	5.0%	8.0%	25.9%	6.2%	1.9%	1.0%	
Control Efficiency						**-11.9%**	**-22.0%**	**96.8%**	**88.8%**			
DASH 8 - NOTCH 8 - 2 CLOUD CHAMBERS												
T0954	9/11/2006 12:25	29,798	121	629	25.0	32,818	141	13.7	3.4	9,510	9,913	96%
Control Efficiency						**-10.1%**	**-15.9%**	**97.8%**	**86.5%**			
DASH 8 - NOTCH 5												
T0941	9/6/2006 18:06	18,058	131	428	3.2	23,600	188	5.3	1.4	5,792	6,152	94%
T0945	9/7/2006 19:32	17,348	122	411	6.5	20,639	151	1.6	1.0	5,562	6,111	91%
T0950	9/9/2006 18:41	18,065	113	438	7.0	20,355	123	13.2	1.2	5,745	6,079	95%
T0956	9/11/2006 15:28	18,971	145	433	5.8	19,697	142	6.8	1.4	6,088	6,218	98%
Average		18,111	128	427	6.4	21,073	151	6.7	1.2	5,797	6,140	94%
Coeff. Of Deviation		3.7%	10.8%	2.7%	8.9%	8.2%	18.0%	71.9%	12.9%	3.8%	1.0%	
Control Efficiency						**-16.4%**	**-18.1%**	**98.4%**	**80.9%**			
DASH 8 - NOTCH 1												
T0943	9/7/2006 13:01	3,961	26	90	4.3	3,539	18	1.4	0.1	1,261	783	161%
T0948	9/9/2006 11:02	3,528	13	106	4.9	3,550	17	0.1	0.1	1,105	799	138%
T0958	9/12/2006 15:25	3,865	13	94	4.7	3,781	19	4.0	0.1	1,232	808	152%
Average		3,785	17	97	4.6	3,623	18	1.9	0.1	1,199	797	150%
Coeff. Of Deviation		6.0%	45.6%	8.4%	6.5%	3.8%	6.0%	107%	2.9%	6.9%	1.6%	
Control Efficiency						**4.3%**	**-3.0%**	**98.1%**	**98.6%**			
DASH 8 SOUPING BASELINE												
T0947	9/9/2006 9:54	11,148	32	271	4.5	11,044	38	0.0	0.3	3,552	3,558	100%
T0957	9/12/2006 14:00	10,825	38	263	3.1	#N/A	#N/A	#N/A	0.4	3,428	#N/A	#N/A
T0960	9/13/2006 13:28	11,087	41	268	3.9	13,094	58	0.0	0.3	3,536	3,510	101%
Average		11,020	37	267	3.8	12,069	48	0.0	0.4	3,505	3,534	99%
Coeff. Of Deviation		1.6%	11.6%	1.6%	18%	12.0%	29.5%	141%	22.0%	1.9%	1.0%	
Control Efficiency						**-9.5%**	**-28.5%**	**100%**	**90.7%**			
DASH 8 SOUPING TEST												
T0944	9/7/2006 18:24	9,926	40	242	10.9	12,864	61	7.5	0.4	3,168	#N/A	#N/A
T0949	9/9/2006 16:30	11,654	33	265	12.1	11,517	53	15.5	0.3	3,687	3,437	107%
T0959	9/12/2006 18:17	10,943	50	265	31.6	13,146	62	0.0	1.0	3,495	3,321	105%
Average		10,841	41	257	18.2	12,509	58	7.7	0.5	3,450	3,379	102%
Coeff. Of Deviation		8.0%	19.8%	5.3%	64%	7.0%	8.7%	101%	65.4%	7.6%	2.4%	
Control Efficiency						**-15.4%**	**-42.6%**	**97.0%**	**97.0%**			

The shaded cells in Table 5 indicate results that were excluded from the averages due to technical problems with the measurements. In Test 941, the PM results were affected by a leak into the PM filter suction when the suction line to the aethelometer became disconnected. Test 946 was the first test conducted at Notch 8, and the resulting exhaust flow was so high that the RAVEM was unable to maintain isokinetic sampling. The outlet RAVEM was originally equipped with a one-inch diameter isokinetic probe to maximize the amount of pollutant collected at low loads. A one-half inch probe was used for subsequent testing at Notch 5 and Notch 8, while the one inch probe continued to be used at lower power settings.

In Test 952, the locomotive engine shut down due to low lube oil pressure at 22 minutes into the test. While this did not affect the validity of the emission results, fuel in the locomotive engine circuit drained back into the day tank after the shutdown, affecting the mass fuel consumption measurement.

RAVEM system results from the stationary testing on the GP38 locomotive are summarized in Table 6. Exhaust mass flow and pollutant flow rates were significantly lower from this 2000 horsepower locomotive than from the 3900 horsepower Dash 8, and both the emission testing crew and the ALECS operations had gained experience during the earlier testing. Fewer technical problems were experienced, therefore, and the carbon balance results show close agreement between the measured and calculated fuel consumption.

The NOx control efficiency of the ALECs system in these tests ranged from 95 to 99%, while the PM control efficiency was 90% or better across all of the test modes. Except at Notch 8, CO emissions were too low to measure accurately, so that the high percentage increases shown for this pollutant are of little actual significance.

RAVEM system results from the moving tests on both locomotives are presented in Table 7. Because of the motion, the day tank had to be disconnected, so that mass fuel consumption measurements were not possible. Since the locomotives were only able to move very slowly, and over a restricted distance, the power required, calculated fuel consumption, and emissions were very low. The mass emission rates and calculated fuel consumption rates are even lower than those for continuous Notch 1 operation. PM and NOx control efficiencies under these conditions were well above 90%.

Table 6: ALECS inlet vs. outlet emissions - RAVEM data for the GP38

Test No.	Start Date/Time	Inlet Emissions (g/min)				Outlet Emissions (g/min)				Inlet Fuel (g/min)		
		CO_2	CO	NOx	PM	CO_2	CO	NOx	PM	Calc.	Meas.	Ratio
GP 38 - NOTCH 8												
T0967	9/16/2006 16:09	18,189	34	462	7.7	20,679	42	16.8	0.5	5,778	6,175	94%
T0968	9/16/2006 17:19	19,535	32	469	6.3	22,153	46	2.1	0.5	6,204	6,167	101%
T0969	9/16/2006 18:18	20,509	44	468	5.7	21,567	48	1.3	0.8	6,518	6,150	106%
Average		19,411	37	466	6.6	21,466	45	6.8	0.6	6,167	6,164	100%
Coeff. Of Deviation		6.0%	18.2%	0.8%	16%	3.5%	6.5%	129%	27.8%	6.0%	0.2%	
Control Efficiency						**-10.6%**	**-24.0%**	**98.6%**	**90.7%**			
GP 38 - NOTCH 5												
T0964	9/16/2006 10:50	9,754	3	201	5.5	10,811	10	0.0	0.4	3,091	3,208	96%
T0965	9/16/2006 12:33	10,036	6	209	4.5	11,281	12	1.4	0.4	3,182	3,178	100%
T0966	9/16/2006 14:18	9,816	1	204	4.0	11,356	18	2.9	0.5	3,110	3,168	98%
Average		9,869	3	205	4.7	11,150	14	1.4	0.4	3,128	3,185	98%
Coeff. Of Deviation		1.5%	77.3%	2.0%	16%	2.6%	32.3%	101%	6.2%	1.5%	0.7%	
Control Efficiency						**-13.0%**	**-324%**	**99.3%**	**90.7%**			
GP 38 - NOTCH 1												
T0962	9/15/2006 16:30	1,600	3	27	0.40	2,292	3	-0.4	0.03	505	438	115%
T0971	9/17/2006 11:43	1,326	2	28	0.20	2,223	3	2.6	0.03	421	430	98%
T0973	9/17/2006 15:27	1,628	(7)	27	0.36	2,256	5	0.3	0.04	509	426	119%
Average		1,518	(1)	27	0.32	2,257	4	0.8	0.03	478	431	111%
Coeff. Of Deviation		11.0%	638%	2.6%	34%	1.5%	31.7%	194%	9.4%	10.4%	1.4%	
Control Efficiency						**-48.7%**	**#N/A**	**97.0%**	**89.6%**			
GP 38 SOUPING BASELINE												
T0961	9/15/2006 15:15	6,085	(1)	114	1.9	6,777	9	2.5	0.2	1,916	1,759	109%
T0970	9/17/2006 10:30	5,316	2	100	1.7	5,971	6	2.3	0.1	1,685	1,765	95%
T0975	9/17/2006 19:10	5,489	3	102	1.4	6,294	8	0.1	0.2	1,740	1,732	100%
Average		5,630	1	106	1.7	6,347	8	1.6	0.2	1,780	1,752	102%
Coeff. Of Deviation		7.2%	159%	7.1%	14%	6.4%	18.9%	79.8%	6.4%	6.8%	1.0%	
Control Efficiency						**-12.7%**	**-474%**	**98.4%**	**90.8%**			
GP 38 SOUPING TEST												
T0963	9/15/2006 19:17	6,222	(2)	109	3.5	6,192	9	12.1	0.1	1,970	1,698	116%
T0972	9/17/2006 14:16	5,065	(1)	96	2.6	6,213	7	2.0	0.2	1,604	1,692	95%
T0974	9/17/2006 18:08	4,694	(2)	93	2.7	5,045	7	0.3	0.1	1,477	1,459	101%
Average		5,327	(2)	99	2.9	5,817	8	4.8	0.1	1,684	1,617	104%
Coeff. Of Deviation		15.0%	55.5%	8.4%	17%	11.5%	13.7%	133%	14.0%	15.2%	8.4%	
Control Efficiency						**-9.2%**	**#N/A**	**95.2%**	**94.9%**			

Table 7: ALECS inlet vs. outlet emissions - RAVEM data for moving tests

Test No.	Start Date/Time	Inlet Emissions (g/min)				Outlet Emissions (g/min)				Inlet Fuel (g/min)		
		CO_2	CO	NOx	PM	CO_2	CO	NOx	PM	Calc.	Meas.	Ratio
DASH 8 MOVING TEST												
T0980	9/20/2006 14:11	2,116	9	51	5.6	2,398	15	1.4	0.0	675	#N/A	#N/A
T0981	9/20/2006 15:28	2,306	10	53	3.1	2,563	14	0.0	0.1	736	#N/A	#N/A
T0982	9/20/2006 16:24	969	(1)	26	1.0	1,947	7	0.3	0.0	307	#N/A	#N/A
Average		1,797	6	43	3.2	2,303	12	0.6	0.0	573	#N/A	#N/A
Coeff. Of Deviation		40.3%	97.6%	35.4%	71%	13.9%	38.9%	129%	16.8%	40.6%	#N/A	
Control Efficiency						**-28.2%**	**-99.4%**	**98.7%**	**98.5%**			
GP 38 MOVING TEST												
T0976	9/19/2006 15:00	1,072	4	22	0.2	1,508	2	2.3	0.0	342	#N/A	#N/A
T0978	9/20/2006 9:41	884	1	23	0.0	1,705	3	0.0	0.0	281	#N/A	#N/A
T0979	9/20/2006 10:52	739	1	21	0.5	1,769	4	0.2	0.0	235	#N/A	#N/A
Average		898	2	22	0.2	1,661	3	0.8	0.0	286	#N/A	#N/A
Coeff. Of Deviation		18.6%	70.9%	6.5%	116%	8.2%	20.1%	158%	66.8%	18.8%	#N/A	
Control Efficiency						**-84.9%**	**-47.7%**	**96.3%**	**93.5%**			

3.2 CEMS RESULTS: NOX, SO_2, THC, AND NH_3

CEMS results for the stationary emission tests on the Dash 8 locomotive are shown in Table 8, while those for the GP38 are shown in Table 9. Results of the moving tests on both locomotives are shown in Table 10. The CEMS data recording was not fully functional during the first few tests in this program, so that these data are shown as #NA in the tables.

The CEMS data, like the RAVEM data, show extremely high control efficiency for NOx. Although SO_2 emissions in these tests were already low, the ALECS system reduced these to barely-detectable levels. Ammonia emissions were also below or close to the limits of detectability over most of the test period. Control of THC emissions was considerably less effective, ranging from about 31% to 85% effective. THC control was least efficient in the test conditions with the highest THC emissions.

Since NOx emissions were measured using both the CEMS and the RAVEM systems, a comparison between these two methods provides insight into the accuracy of the measurements. Figure 3 is a cross-plot of the NOx emission rate at the ALECS inlet as measured by the CEMS vs. that measured by the RAVEM. As this figure shows, the relationship is nearly 1:1, except at the highest NOx flow rates (measured at Notch 8 on the Dash 8 locomotive), where the CEMS results are about 12% higher. Since the carbon balance data for the RAVEM agree closely with the mass fuel consumption measurements, it is likely that the error lies in the CEMS data. This discrepancy may be due to excess water vapor from water injected into the exhaust duct to protect it from overheating. This would have had the effect of increasing apparent exhaust flow through the venturi. According to ACTI personnel, water injection was done only at high load, and the amount of water injected was not measured.

Table 8: ALECS inlet vs. outlet emissions - CEMS data for the Dash 8

Test No.	Start Date/Time	Inlet (g/min) NOx	Inlet (g/min) SO_2	Inlet (g/min) THC	Outlet (g/min) NOx	Outlet (g/min) SO_2	Outlet (g/min) THC	Outlet (g/min) NH3	Flow SCFM Inlet	Flow SCFM Outlet
DASH 8 - NOTCH 8										
T0946	9/8/2006 18:29	732.9	31.06	#N/A	31.5	0.00	7.11	1.1	12,829	14,011
T0951	9/10/2006 10:44	737.4	29.12	13.26	26.2	0.30	6.76	1.2	12,365	14,010
T0952	9/10/2006 12:23	725.9	26.18	9.87	16.5	0.00	7.39	1.6	12,028	13,941
T0953	9/11/2006 11:23	727.3	26.68	8.11	24.8	0.00	6.41	1.1	12,115	13,992
T0955	9/11/2006 13:33	710.9	23.68	8.36	14.6	0.00	6.02	1.2	11,801	13,812
Average		726.9	27.34	9.90	22.7	0.07	6.64	1.3	12,077	13,939
Coeff. Of Deviation		1.4%	10.4%	24.0%	31.0%	198.7%	8.7%	17.8%	1.9%	0.6%
Control Efficiency					**96.9%**	**99.7%**	**32.9%**			
DASH 8 - NOTCH 8 - 2 CLOUD CHAMBERS										
T0954	9/11/2006 12:25	718.8	25.19	8.05	15.9	0.00	6.16	1.8	11,983	13,898
Control Efficiency					**97.8%**	**100.0%**	**23.5%**			
DASH 8 - NOTCH 5										
T0941	9/6/2006 18:06	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
T0945	9/7/2006 19:32	#N/A	19.23	#N/A	1.1	0.00	1.58	1.7	7,515	8,040
T0950	9/9/2006 18:41	462.7	18.82	4.02	9.4	0.00	3.46	0.8	7,015	8,140
T0956	9/11/2006 15:28	469.6	16.43	4.10	6.1	0.00	3.33	0.0	6,998	8,173
Average		466.1	#N/A	4.06	5.5	0.00	2.79	0.8	7,176	8,117
Coeff. Of Deviation		1.0%	#N/A	1.3%	75.2%	173.2%	37.7%	103.9%	4.1%	0.9%
Control Efficiency					**98.8%**	**#N/A**	**31.4%**			
DASH 8 - NOTCH 1										
T0943	9/7/2006 13:01	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
T0948	9/9/2006 11:02	52.8	1.48	1.08	1.3	0.02	0.73	0.0	2,257	2,948
T0958	9/12/2006 15:25	57.1	1.39	1.70	2.5	0.00	0.45	0.6	2,326	2,936
Average		55.0	1.44	1.39	1.9	0.01	0.59	0.3	2,291	2,942
Coeff. Of Deviation		5.5%	4.3%	31.5%	47.5%	97.4%	33.4%	136.0%	2.1%	0.3%
Control Efficiency					**96.5%**	**99.1%**	**57.6%**			
DASH 8 SOUPING BASELINE										
T0947	9/9/2006 9:54	277.2	12.68	#N/A	0.1	0.00	2.27	0.0	4,417	4,699
T0957	9/12/2006 14:00	278.6	9.97	3.84	3.0	0.00	2.77	0.0	4,169	4,540
T0960	9/13/2006 13:28	277.2	9.95	3.95	0.2	0.00	2.94	0.0	4,221	4,516
Average		277.7	10.87	3.90	1.1	0.00	2.60	0.0	4,319	4,607
Coeff. Of Deviation		0.3%	14.4%	2.1%	152.6%	0.0%	13.5%	115.2%	3.0%	2.2%
Control Efficiency					**99.6%**	**100.0%**	**33.2%**			
DASH 8 SOUPING TEST										
T0944	9/7/2006 18:24	#N/A	9.75	#N/A	3.1	0.04	1.43	0.2	4,333	4,378
T0949	9/9/2006 16:30	255.5	9.80	4.89	7.1	0.16	3.09	0.1	4,095	4,437
T0959	9/12/2006 18:17	244.9	8.71	4.33	6.5	0.02	2.20	0.0	3,980	4,354
Average		250.2	9.42	4.61	5.6	0.07	2.24	0.1	4,136	4,390
Coeff. Of Deviation		3.0%	6.6%	8.7%	39.3%	104.9%	37.0%	75.5%	4.4%	1.0%
Control Efficiency					**97.8%**	**99.2%**	**51.4%**			

Table 9: ALECS inlet vs. outlet emissions - CEMS data for the GP 38

Test No.	Start Date/Time	Inlet (g/min) NOx	Inlet (g/min) SO_2	Inlet (g/min) THC	Outlet (g/min) NOx	Outlet (g/min) SO_2	Outlet (g/min) THC	Outlet (g/min) NH3	Flow SCFM Inlet	Flow SCFM Outlet
GP 38 - NOTCH 8										
T0967	9/16/2006 16:09	490.3	16.26	3.74	14.4	0.00	0.92	0.0	8,376	9,413
T0968	9/16/2006 17:19	486.6	16.19	3.23	1.5	0.00	0.89	0.0	8,288	9,369
T0969	9/16/2006 18:18	480.9	16.25	3.17	0.9	0.00	0.91	0.4	8,270	9,355
Average		485.9	16.23	3.38	5.6	0.00	0.90	0.1	8,311	9,379
Coeff. Of Deviation		1.0%	0.2%	9.3%	136.0%	0.00	1.7%	173.1%	0.7%	0.3%
Control Efficiency					**98.8%**	**100.0%**	**73.2%**			
GP 38 - NOTCH 5										
T0964	9/16/2006 10:50	196.9	4.73	1.47	0.3	0.00	0.22	0.0	6,522	7,023
T0965	9/16/2006 12:33	202.0	4.75	1.66	1.0	0.00	0.23	0.0	6,320	6,924
T0966	9/16/2006 14:18	204.8	4.63	1.71	2.2	0.00	0.24	0.0	6,270	6,889
Average		201.2	4.70	1.62	1.2	0.00	0.23	0.0	6,371	6,945
Coeff. Of Deviation		2.0%	1.4%	7.8%	79.9%	0.00	2.4%	99.0%	2.1%	1.0%
Control Efficiency					**99.4%**	**100.0%**	**85.7%**			
GP 38 - NOTCH 1										
T0962	9/15/2006 16:30	21.0	0.27	0.46	0.07	0.06	0.08	0.0	3,286	3,827
T0971	9/17/2006 11:43	21.6	0.12	0.50	1.73	0.00	0.10	1.9	3,735	4,245
T0973	9/17/2006 15:27	21.8	0.11	0.60	0.08	0.00	0.09	0.0	3,677	4,193
Average		21.5	0.17	0.52	0.63	0.02	0.09	0.6	3,566	4,088
Coeff. Of Deviation		1.9%	52.4%	13.9%	152.6%	173.2%	11.2%	169.1%	6.8%	5.6%
Control Efficiency					**97.1%**	**88.4%**	**83.1%**			
GP 38 SOUPING BASELINE										
T0961	9/15/2006 15:15	98.6	1.66	0.99	2.5	0.00	0.13	0.0	4,802	5,197
T0970	9/17/2006 10:30	97.5	1.24	0.84	2.3	0.00	0.14	0.1	5,872	6,355
T0975	9/17/2006 19:10	97.9	1.13	1.01	0.1	0.00	0.16	0.0	5,493	6,037
Average		98.0	1.35	0.95	1.6	0.00	0.14	0.0	5,389	5,863
Coeff. Of Deviation		0.6%	20.9%	9.7%	80.6%	0.0%	10.6%	157.3%	10.1%	10.2%
Control Efficiency					**98.3%**	**100.0%**	**84.9%**			
GP 38 SOUPING TEST										
T0963	9/15/2006 19:17	86.5	1.44	0.92	9.4	0.14	0.14	0.3	4,962	5,399
T0972	9/17/2006 14:16	92.0	0.99	1.02	1.3	0.00	0.15	0.0	5,620	6,135
T0974	9/17/2006 18:08	92.5	1.00	0.98	0.2	0.00	0.17	0.3	5,486	5,987
Average		90.3	1.14	0.97	3.6	0.05	0.15	0.2	5,356	5,840
Coeff. Of Deviation		3.7%	22.2%	5.3%	137.2%	173.2%	7.4%	87.6%	6.5%	6.7%
Control Efficiency					**96.0%**	**96.0%**	**84.2%**			

A cross-plot of the outlet NOx concentrations measured by the CEMS vs. the RAVEM shows a similar 1:1 relationship, but with much greater variability, due to the low NOx concentrations involved.

Table 10: ALECS inlet vs. outlet emissions - CEMS data for the moving tests

Test No.	Start Date/Time	Inlet (g/min)			Outlet (g/min)				Flow SCFM	
		NOx	SO_2	THC	NOx	SO_2	THC	NH3	Inlet	Outlet
DASH 8 MOVING TEST										
T0980	9/20/2006 14:11	36.4	0.94	1.67	1.1	0.00	0.91	0.000	2,645	3,154
T0981	9/20/2006 15:28	35.4	0.88	1.36	0.1	0.00	0.53	0.000	2,458	2,946
T0982	9/20/2006 16:24	19.5	0.44	0.78	0.2	0.00	0.23	0.000	2,196	2,838
Average		30.4	0.75	1.27	0.4	0.00	0.56	0.000	2,433	2,979
Coeff. Of Deviation		31.2%	36.6%	35.3%	131.5%	0.0%	60.9%	100.2%	9.3%	5.4%
Control Efficiency					**98.5%**	**100.0%**	**56.0%**			
GP 38 MOVING TEST										
T0976	9/19/2006 15:00	17.1	0.22	0.47	2.1	0.00	0.11	0.001	3,636	4,177
T0978	9/20/2006 9:41	17.2	0.27	0.46	0.1	0.11	0.10	0.000	3,905	4,401
T0979	9/20/2006 10:52	16.0	0.25	0.46	0.1	0.00	0.09	0.000	3,843	4,331
Average		16.8	0.24	0.46	0.8	0.04	0.10	0.000	3,795	4,303
Coeff. Of Deviation		4.1%	9.1%	1.1%	154.8%	173.2%	9.6%	139.2%	3.7%	2.7%
Control Efficiency					**95.4%**	**84.9%**	**78.6%**			

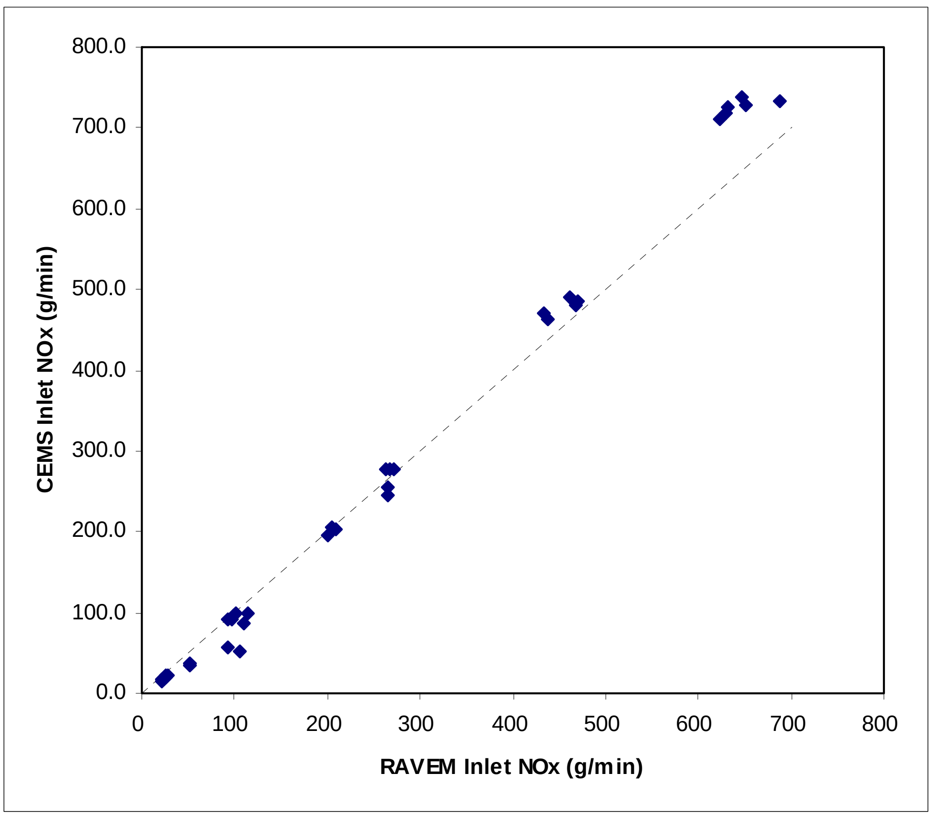

Figure 3: CEMS vs. RAVEM NOx measurements

3.3 FTIR RESULTS: NH_3 AND N_2O

FTIR measurements of ammonia and N_2O concentrations were carried out alternately on the outlet and inlet gas streams in parallel with tests 964 through 979. The ammonia concentrations measured by the FTIR system were extremely low (generally in the range of zero to 2 ppm), and consistent with the results of the chemilumenescent ammonia analyzer incorporated in the CEMS system. The N_2O concentrations reported by the FTIR system were also generally in the range of zero to 2 ppm, and less than the estimated error calculated by the FTIR software. N_2O concentrations measured at the ALECS inlet were similar to those measured at the outlet, suggesting that the reported values were likely due to the presence of interfering species rather than N_2O as such.

3.4 SOUPING EMISSIONS: PM BUILDUP DURING NOTCH 1

During prolonged periods of low-load operation, particulate matter (mostly semi-volatile hydrocarbons) tends to build up on the walls of the exhaust system, forming a liquid deposit, colloquially known as “soup”. Since locomotives are often left idling for long periods, substantial amounts of material can build up. Once the locomotive returns to higher-load operation, the accumulated material comes back off of the walls and into the exhaust. If soup deposits are heavy, some of this material is blown out of the exhaust system as large liquid droplets. Much of it, however, is emitted as fine particulate matter, forming a transient cloud of visible white or gray smoke during the first seconds after the engine load increases.

The transient PM spike due to re-mobilization of the soup deposits is not captured by the present Federal test procedure for locomotives, since it measures emissions only under stabilized conditions. Previous testing by EF&EE[2] showed that these soup emissions can be significant: accounting for 0.10 and 0.19 grams per minute (15% and 49% of idling PM emissions, respectively) from two turbocharged EMD locomotives.

To determine the PM emissions in this test program due to soup buildup, we compared the PM results at Notch 3 in the souping baseline tests with those measured in the souping tests, going from Notch 1 to Notch 3 after a prolonged period of Notch 1 operation. This calculation is shown in Table 11. Average PM emissions during the baseline tests on each locomotive were subtracted from the measured PM emissions during the souping test to calculate the excess PM emission due to soup buildup. This excess was then divided by the length of the preceding buildup period to calculate the rate of soup PM buildup for per minute of Notch 1 operation.

As Table 11 shows, the PM emissions attributable to souping in the GP38 are comparable to those measured in our earlier study, averaging 0.38 g/min or 38% of total Notch 1 PM emissions attributable to Notch 1 operation. Souping emissions from the Dash 8 locomotive were much higher, but the Notch 1 PM emissions were higher still, so that souping accounted for only 26% of the Notch 1 PM emissions attributable to this locomotive (see Table 12). The souping emissions from the Dash 8 also exhibited great variability, with one test producing seven times higher emissions than the other two. Such a large discrepancy normally suggests a measurement error, such as an error in PM filter handling or weighing. That is not a likely explanation in this case, however, since the higher PM emissions were also observed in the RAVEM measurements on the ALECS outlet.

Table 11: Calculation of "soup" PM buildup during Notch 1 operation

Test No	Buildup (minutes)	ALECS Inlet PM (g)			Souping g/min	ALECS Outlet PM (g)			Souping g/min
		Total	Baseline	Excess		Total	Baseline	Excess	
Dash 8									
944	435.6	326.5	115.1	211.4	0.49	11.0	10.7	0.3	0.001
949	366.3	362.5	115.1	247.5	0.68	9.4	10.7	-1.3	-0.004
959	227.3	950.9	115.1	835.7	3.68	28.6	10.7	17.9	0.079
GP 38									
963	211.5	105.2	50.4	54.8	0.26	4.2	4.6	-0.5	-0.002
972	195.5	76.7	50.4	26.3	0.13	5.2	4.6	0.6	0.003
974	202.2	81.7	50.4	31.3	0.15	4.1	4.6	-0.5	-0.003

Table 12: Souping PM as percentage of total PM emissions during Notch 1

Locomotive	Notch 1 PM Emissions (g/min)			Soup as Pct of Total
	Direct	Soup	Total	
ALECS Inlet				
Dash 8	4.64	1.61	6.25	26%
GP 38	0.32	0.18	0.50	37%
ALECS Outlet				
Dash 8	0.07	0.025	0.09	27%
GP 38	0.03	-0.001	0.03	-2%

As Tables 11 and 12 show, the ALECS system was nearly 100% effective in controlling the incremental emissions due to soup buildup and re-entrainment. This suggests that it would be good policy, after a prolonged idle period, to run locomotives at Notch 3 for a few minutes before disconnecting them from the ALECS system.

3.5 RAVEM Measurements in the Locomotive Stack vs. ALECS Inlet

To determine whether the emission measurements at the ALECS inlet had been affected by the passage of exhaust through the exhaust duct, RAVEM emission measurements were also conducted at the locomotive exhaust stack. In the case of the Dash 8, these measurements faced a number of complications. First, the exhaust composition is not homogeneous in the exhaust stack. As can be seen in Figure 4, the venturi effect of the exhaust velocity provides suction for the crankcase vent tube (right) and three tubes coming from the air cleaner. The function of these latter tubes is unknown, but they appear to carry a significant flow of air into the exhaust. The RAVEM probe was located on the centerline between the left and right sides, but could still have been affected by special variation in the velocity and chemical composition of the exhaust.

Installation of the RAVEM probe on the GP 38 was also complicated, since the GP38 has two round exhaust stacks. This required the use of two probes, with the raw exhaust lines connected together in a T configuration. Two of the four delta-pressure lines from the isokinetic sampler were connected to each probe to maintain approximately isokinetic sampling, but this arrangement would not have been able to compensate for any substantial difference in exhaust velocity between the two stacks.

Figure 4: View into the Dash 8 exhaust stack, showing the crankcase vent and air filter suction tubes

Another complicating factor was the interaction between the ALECS hoods and the sample lines and delta-pressure lines of the RAVEM system. The magnets on the hood hold it to the locomotive with considerable force, and this resulted in the crushing of the sample or delta-pressure lines on several occasions. In retrospect, a preferable approach would have been to install the probes in the hood of the ALECS system instead of directly in the stack.

Table 13 compares the NO, PM, and CO_2 emissions measured at the locomotive stack and at the inlet to the ALECS system. Because of the uncertainties involved in sampling directly from the stacks, it is more useful to compare the pollutant-to-CO_2 ratios measured in these two locations rather than the mass emissions as such. As Table 13 shows, the NOx to CO_2 ratios measured in the two locations generally agree well. However, the PM-to-CO_2 ratio measured in the stack is generally lower than that in measured at the ALECS inlet.

Table 13: RAVEM measurements at the locomotive stack vs. inlet emissions

Test No.	Inlet (g/min)			Stack (g/min)			PM/CO_2		NOx/CO_2	
	CO_2	NOx	PM	CO_2	NOx	PM	Inlet	Stack	Inlet	Stack
DASH 8 - NOTCH 1										
T0958	3865	93.7	4.72	662	17.8	0.60	1.22	0.91	24.24	26.81
DASH 8 SOUPING TEST										
T0959	10943	264.9	31.64	4465	110.2	1.16	2.89	0.26	24.21	24.68
DASH 8 MOVING TEST										
T0980	2116	51.0	5.62	2980	72.8	6.59	2.66	2.21	24.12	24.43
T0981	2306	52.8	3.09	3617	88.9	4.11	1.34	1.14	22.90	24.57
T0982	969	25.5	1.02	2906	65.3	2.06	1.06	0.71	26.37	22.45
GP 38 - NOTCH 5										
T0964	9754	200.6	5.46	#N/A	#N/A	5.16	0.56	#N/A	20.56	#N/A
T0965	10036	208.6	4.52	9412	162.1	3.70	0.45	0.39	20.79	17.22
T0966	9816	204.5	4.01	4249	80.2	2.41	0.41	0.57	20.83	18.87
GP 38 - NOTCH 1										
T0962	1600	26.7	0.40	1162	18.8	0.21	0.25	0.18	16.70	16.22
GP 38 SOUPING BASELINE										
T0961	6085	114.1	1.92	4778	81.1	1.43	0.32	0.30	18.76	16.97
GP 38 SOUPING TEST										
T0963	6222	108.9	3.50	3594	60.1	2.56	0.56	0.71	17.50	16.72
GP 38 MOVING TEST										
T0976	1072	21.6	0.17	620	11.9	0.22	0.16	0.36	20.11	19.16
T0978	884	23.4	0.00	750	14.9	0.23	0.00	0.30	26.46	19.80
T0979	739	20.6	0.52	759	14.7	0.25	0.71	0.33	27.89	19.41

4. NOISE MEASUREMENTS

Locomotive noise emissions were measured using a Larson-Davis model 720 sound level meter. The meter was calibrated before use. The time-weighted average equivalent sound level (Leq) was measured over a three minute period, using the "A" frequency weighting filter. Emission measurements were made at a point 30 meters away from the locomotive, and along a line passing through the center of the locomotive perpendicular to the track, as specified in 40 CFR 201.20 et seq. To minimize the effects of background noise, measurements were taken only when no trains were operating nearby. However, it was not possible to eliminate the noise from other locomotives idling in the vicinity.

The purpose of the noise measurements was to assess the noise reduction due to the exhaust hood, especially the noise experienced during power tests at Notch 8. Noise was measured both with the hood in place, and with the hood raised approximately two feet above the exhaust stack. The results are summarized in Table 14. Due to the silencing effect of its turbocharger, the Dash 8 had noticeably less exhaust noise than the GP38. For the GP38 at full power, and the Dash 8 at part-load, the exhaust hood reduced the average sound level by 6.8 dB(A). Since the dB measurement is logarithmic, this is equivalent to an actual 79% reduction in sound power level. For the Dash 8 at full load, non-exhaust sources such as cooling fans contributed significantly to the overall noise level, so that the percentage reduction was less.

Table 14: Noise measurements with and without the hood in place

	Leq dB(a)			**Pct Red. In**
	w/o Hood	**w Hood**	**Reduction**	**Sound Energy**
Dash 8				
Notch 8	87.0	81.7	5.3	70%
Notch 5	84.5	77.7	6.8	79%
GP 38				
Notch 8	91.6	84.8	6.8	79%

5. REFERENCES

[1] California Air Resources Board, Roseville Railyard Study, October, 2004.

[2] C.S. Weaver and L.E. Petty, Start-Up and Idling Emissions from Two Locomotives, report under South Coast Air Quality Management District contract No. 00112, Engine, Fuel, and Emissions Engineering, Inc. January 16, 2006.

Appendix C. Laboratory Report of Fuel Analysis

Saybolt
A CORE LABORATORIES COMPANY

SAYBOLT LP
21730 S. Wilmington Avenue
Suite 201
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310-518-4400 Telephone
310-518-4455 Facsimile

Fast To The Point

Saybolt LP

Certificate of Analysis

ENGING, FUEL & EMISSIONS ENGINEERING, INC.
LARRY PETTY
3215 LUYUNG DRIVE
RANCHO CORDOVA, CA 95742

ORIGINAL

Report Date:	9/30/2006	Date Sampled:	
Job No:	13091-00002913	Product:	Diesel Fuel
Sample Number:	601719-01	Location:	Rancho Cordova, CA
Client Ref:		Sample ID:	Desl- 8 # 1
		Vessel:	

Test	Method	Result	Units
Carbon/Hydrogen /Nitrogen Content			
Carbon Content	ASTM D-5291M	86.00	wt%
Hydrogen Content	ASTM D-5291M	13.33	wt%
Nitrogen Content	ASTM D-5291M	0.05	wt%
Total Sulfur	ASTM D-4294	0.060	wt%

*Analysis results for D5291M are submitted by a third party laboratory. Saybolt was not present whilst the analysis was carried out, and has signed for receipt only with no liability accepted.

Approved By: Signature On File
Ken Nabl
Laboratory Manager

Saybolt
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Fast To The Point

Saybolt LP

Certificate of Analysis

ENGING, FUEL & EMISSIONS ENGINEERING, INC.
LARRY PETTY
3215 LUYUNG DRIVE
RANCHO CORDOVA, CA 95742

		Date Sampled:	
Report Date:	9/30/2006	Product:	Diesel Fuel
Job No:	13091-00002913	Location:	Rancho Cordova, CA
Sample Number:	601719-02	Sample ID:	TP38
Client Ref:		Vessel:	

Test	Method	Result	Units
Carbon/Hydrogen /Nitrogen Content			
Carbon Content	ASTM D-5291M	86.10	wt%
Hydrogen Content	ASTM D-5291M	13.73	wt%
Nitrogen Content	ASTM D-5291M	0.06	wt%
Total Sulfur	ASTM D-4294	<0.0150	wt%

*Analysis results for D5291M are submitted by a third party laboratory. Saybolt was not present whilst the analysis was carried out, and has signed for receipt only with no liability accepted.

Approved By: Signature On File
Ken Nabl
Laboratory Manager

Appendix D. Laboratory Reports on Solid and Wastewater Analyses

CAL TECH Environmental Laboratories
6814 Rosecrans Avenue, Paramount, CA 90723-3146
Telephone: (562) 272-2700 Fax: (562) 272-2789

ANALYTICAL RESULTS*

CTEL Project No: CT-0701092
Client Name: ACTI
18414 S. Santa Fe Ave.
Rancho Dominguez, CA 90221
Attention: Mr. John Powel

Phone:(310) 763-1423
Fax: (310) 763-9076

Project ID:
Project Name: UPRP

Date Sampled: 01/05/07 @ 13:00 p.m.
Date Received: 01/12/07 @ 17:00 p.m.
Date Analyzed 01/12/07 – 01/18/07

Matrix: Solid

Laboratory ID:	0701-092-1	0701-092-2	**Method**	**Units:**	**Detection Limit**
Client Sample ID:	ROC #89	R21 #7			
Dilution	100	100			
Dichlorodifluoromethane	ND	ND	EPA 8260B	mg/Kg	0.005
Chloromethane	ND	ND	EPA 8260B	mg/Kg	0.005
Vinyl Chloride	ND	ND	EPA 8260B	mg/Kg	0.005
Bromomethane	ND	ND	EPA 8260B	mg/Kg	0.005
Chloroethane	ND	ND	EPA 8260B	mg/Kg	0.005
Trichlorofluoromethane	ND	ND	EPA 8260B	mg/Kg	0.005
Iodomethane	ND	ND	EPA 8260B	mg/Kg	0.005
Acetone	ND	ND	EPA 8260B	mg/Kg	0.005
1,1-Dichloroethene	ND	ND	EPA 8260B	mg/Kg	0.005
t-Butyl Alcohol (TBA)	ND	ND	EPA 8260B	mg/Kg	0.020
Methylene Chloride	ND	ND	EPA 8260B	mg/Kg	0.02
Freon 113	ND	ND	EPA 8260B	mg/Kg	0.01
Carbon disulfide	ND	ND	EPA 8260B	mg/Kg	0.005
Trans,1,2-Dichloroethene	ND	ND	EPA 8260B	mg/Kg	0.005
Methyl-tert-butyl-ether(MtBE)	ND	ND	EPA 8260B	mg/Kg	0.002
1,1-Dichloroethane	ND	ND	EPA 8260B	mg/Kg	0.005
Vinyl acetate	ND	ND	EPA 8260B	mg/Kg	0.005
Diisopropyl Ether (DIPE)	ND	ND	EPA 8260B	mg/Kg	0.002
Methyl Ethyl Ketone	ND	ND	EPA 8260B	mg/Kg	0.01
Cis,1,2-Dichloroethene	ND	ND	EPA 8260B	mg/Kg	0.005
Bromochloromethane	ND	ND	EPA 8260B	mg/Kg	0.005
Chloroform	ND	ND	EPA 8260B	mg/Kg	0.005
2,2-Dichloropropane	ND	ND	EPA 8260B	mg/Kg	0.005
Ethyl-t-butyl ether (ETBE)	ND	ND	EPA 8260B	mg/Kg	0.002
1,1,1-Trichloroethane	ND	ND	EPA 8260B	mg/Kg	0.005
1,2-Dichloroethane	ND	ND	EPA 8260B	mg/Kg	0.005
1,1-Dichloropropene	ND	ND	EPA 8260B	mg/Kg	0.005
Carbon Tetrachloride	ND	ND	EPA 8260B	mg/Kg	0.005
Benzene	ND	ND	EPA 8260B	mg/Kg	0.001
t-Amyl Methyl Ether (TAME)	ND	ND	EPA 8260B	mg/Kg	0.002
1,2-Dichloropropane	ND	ND	EPA 8260B	mg/Kg	0.005
Trichloroethene	ND	ND	EPA 8260B	mg/Kg	0.005
Dibromomethane	ND	ND	EPA 8260B	mg/Kg	0.005
Bromodichloromethane	ND	ND	EPA 8260B	mg/Kg	0.005
2-Chloroethylvinylether	ND	ND	EPA 8260B	mg/Kg	0.005
Cis, 1,3-Dichloropropene	ND	ND	EPA 8260B	mg/Kg	0.005
4-Methyl-2-pentanone(MI)	ND	ND	EPA 8260B	mg/Kg	0.01
Trans,1,3-Dichloropropene	ND	ND	EPA 8260B	mg/Kg	0.005
Toluene	ND	ND	EPA 8260B	mg/Kg	0.001
1,1,2-Trichloroethane	ND	ND	EPA 8260B	mg/Kg	0.005

CTEL Project No: CT-0701092

Project ID:
Project Name: UPRP

Laboratory ID: / Client Sample ID:	0701-092-1 ROC #89	0701-092-2 R21 #7	Method	Units	Detection Limit
1,2-Dibromoethane(EDB)	ND	ND	EPA 8260B	mg/Kg	0.005
1,3-Dichloropropane	ND	ND	EPA 8260B	mg/Kg	0.005
Dibromochloromethane	ND	ND	EPA 8260B	mg/Kg	0.005
2-Hexanone	ND	ND	EPA 8260B	mg/Kg	0.01
Tetrachloroethene	ND	ND	EPA 8260B	mg/Kg	0.005
Chlorobenzene	ND	ND	EPA 8260B	mg/Kg	0.005
1,1,1,2-Tetrachloroethane	ND	ND	EPA 8260B	mg/Kg	0.005
Ethylbenzene	ND	ND	EPA 8260B	mg/Kg	0.001
m.p-Xylene	ND	ND	EPA 8260B	mg/Kg	0.001
Bromoform	ND	ND	EPA 8260B	mg/Kg	0.005
Styrene	ND	ND	EPA 8260B	mg/Kg	0.005
o-Xylene	ND	ND	EPA 8260B	mg/Kg	0.001
1,1,2,2-Tetrachloroethane	ND	ND	EPA 8260B	mg/Kg	0.005
1,2,3-Trichloropropane	ND	ND	EPA 8260B	mg/Kg	0.005
Isopropylbenzene	ND	ND	EPA 8260B	mg/Kg	0.005
Bromobenzene	ND	ND	EPA 8260B	mg/Kg	0.005
2-Chlorotoluene	ND	ND	EPA 8260B	mg/Kg	0.005
n-Propylbenzene	ND	ND	EPA 8260B	mg/Kg	0.005
4-Chlorotoluene	ND	ND	EPA 8260B	mg/Kg	0.005
1,3,5-Trimethylbenzene	ND	ND	EPA 8260B	mg/Kg	0.005
Tert-Butylbenzene	ND	ND	EPA 8260B	mg/Kg	0.005
1,2,4-Trimethylbenzene	ND	ND	EPA 8260B	mg/Kg	0.005
Sec-Butylbenzene	ND	ND	EPA 8260B	mg/Kg	0.005
1,3-Dichlorobenzene	ND	ND	EPA 8260B	mg/Kg	0.005
1,4-Dichlorobenzene	ND	ND	EPA 8260B	mg/Kg	0.005
p-Isopropyltoluene	ND	ND	EPA 8260B	mg/Kg	0.005
1,2-Dichlorobenzene	ND	ND	EPA 8260B	mg/Kg	0.005
n-Butylbenzene	ND	ND	EPA 8260B	mg/Kg	0.005
1,2 Dibromo-3-Chloropropane	ND	ND	EPA 8260B	mg/Kg	0.005
1,2,4-Trichlorobenzene	ND	ND	EPA 8260B	mg/Kg	0.005
Naphthalene	ND	ND	EPA 8260B	mg/Kg	0.005
1,2,3-Trichlorobenzene	ND	ND	EPA 8260B	mg/Kg	0.005
Hexachlorobutadiene	ND	ND	EPA 8260B	mg/Kg	0.005
Oil & Grease	85000	78000	EPA 413.2	mg/Kg	10
TRPH	88000	80000	EPA 418.1	mg/Kg	10

ND = Not Detected at the indicated Detection Limit

SURROGATE SPIKE	% SURROGATE RECOVERY		Control Limit
Dibromofluoromethane	97	96	70-130
1,2 Dichloromethaned4	119	120	70-130
Toluene-d8	101	102	70-130
Bromofluorobenzene	113	115	70-130

CTEL Project No: CT-0701092

Project ID:
Project Name: UPRP

Laboratory ID: / Client Sample ID:	0701-092-1 ROC #89	0701-092-2 R21 #7	Method	Units	Detection Limit
1,2-Dibromoethane(EDB)	ND	ND	EPA 8260B	mg/Kg	0.005
1,3-Dichloropropane	ND	ND	EPA 8260B	mg/Kg	0.005
Dibromochloromethane	ND	ND	EPA 8260B	mg/Kg	0.005
2-Hexanone	ND	ND	EPA 8260B	mg/Kg	0.01
Tetrachloroethene	ND	ND	EPA 8260B	mg/Kg	0.005
Chlorobenzene	ND	ND	EPA 8260B	mg/Kg	0.005
1,1,1,2-Tetrachloroethane	ND	ND	EPA 8260B	mg/Kg	0.005
Ethylbenzene	ND	ND	EPA 8260B	mg/Kg	0.001
m.p-Xylene	ND	ND	EPA 8260B	mg/Kg	0.001
Bromoform	ND	ND	EPA 8260B	mg/Kg	0.005
Styrene	ND	ND	EPA 8260B	mg/Kg	0.005
o-Xylene	ND	ND	EPA 8260B	mg/Kg	0.001
1,1,2,2-Tetrachloroethane	ND	ND	EPA 8260B	mg/Kg	0.005
1,2,3-Trichloropropane	ND	ND	EPA 8260B	mg/Kg	0.005
Isopropylbenzene	ND	ND	EPA 8260B	mg/Kg	0.005
Bromobenzene	ND	ND	EPA 8260B	mg/Kg	0.005
2-Chlorotoluene	ND	ND	EPA 8260B	mg/Kg	0.005
n-Propylbenzene	ND	ND	EPA 8260B	mg/Kg	0.005
4-Chlorotoluene	ND	ND	EPA 8260B	mg/Kg	0.005
1,3,5-Trimethylbenzene	ND	ND	EPA 8260B	mg/Kg	0.005
Tert-Butylbenzene	ND	ND	EPA 8260B	mg/Kg	0.005
1,2,4-Trimethylbenzene	ND	ND	EPA 8260B	mg/Kg	0.005
Sec-Butylbenzene	ND	ND	EPA 8260B	mg/Kg	0.005
1,3-Dichlorobenzene	ND	ND	EPA 8260B	mg/Kg	0.005
1,4-Dichlorobenzene	ND	ND	EPA 8260B	mg/Kg	0.005
p-Isopropyltoluene	ND	ND	EPA 8260B	mg/Kg	0.005
1,2-Dichlorobenzene	ND	ND	EPA 8260B	mg/Kg	0.005
n-Butylbenzene	ND	ND	EPA 8260B	mg/Kg	0.005
1,2 Dibromo-3-Chloropropane	ND	ND	EPA 8260B	mg/Kg	0.005
1,2,4-Trichlorobenzene	ND	ND	EPA 8260B	mg/Kg	0.005
Naphthalene	ND	ND	EPA 8260B	mg/Kg	0.005
1,2,3-Trichlorobenzene	ND	ND	EPA 8260B	mg/Kg	0.005
Hexachlorobutadiene	ND	ND	EPA 8260B	mg/Kg	0.005
Oil & Grease	85000	78000	EPA 413.2	mg/Kg	10
TRPH	88000	80000	EPA 418.1	mg/Kg	10

ND = Not Detected at the indicated Detection Limit

SURROGATE SPIKE	% SURROGATE RECOVERY		Control Limit
Dibromofluoromethane	97	96	70-130
1,2 Dichloromethaned4	119	120	70-130
Toluene-d8	101	102	70-130
Bromofluorobenzene	113	115	70-130

CALIFORNIA LABORATORY SERVICES

3249 Fitzgerald Road Rancho Cordova, CA 95742

January 09, 2007

CLS Work Order #: CPJ0336
COC #: 76759

Robert Puga
ACTI
18414 So. Santa Fe Avenue
Rancho Dominguez, CA 90221

Project Name: Alecs

Enclosed are the results of analyses for samples received by the laboratory on 10/09/06 17:35. Samples were analyzed pursuant to client request utilizing EPA or other ELAP approved methodologies. I certify that the results are in compliance both technically and for completeness.

Analytical results are attached to this letter. Please call if we can provide additional assistance.

Sincerely,

James Liang, Ph.D.
Laboratory Director

CA DOHS ELAP Accreditation/Registration number 1233

CALIFORNIA LABORATORY SERVICES

01/09/07 09:13

ACTI 18414 So. Santa Fe Avenue Rancho Dominguez, CA 90221	Project: Alecs Project Number: [none] Project Manager: Robert Puga	**CLS Work Order #: CPJ0336** COC #: 76759

Conventional Chemistry Parameters by APHA/EPA Methods

Analyte	Result	Reporting Limit	Units	Dilution	Batch	Prepared	Analyzed	Method	Notes
East Side Tank (CPJ0336-01) Water Sampled: 10/09/06 16:35 Received: 10/09/06 17:35									
Specific Conductance (EC)	**2300**	1.0	µmhos/cm	1	CP07821	10/10/06	10/10/06	EPA 120.1	
Fluoride	**2.5**	2.0	mg/L	20	CP07801	10/10/06	10/10/06	EPA 300.0	
Chloride	**17**	10	"	"	"	"	"	"	
Nitrite as NO2	**500**	50	"	100	"	"	"	"	
Bromide	**0.59**	0.10	"	1	"	"	"	"	
Nitrate as NO3	**1.5**	0.50	"	"	"	"	"	"	
Sulfate as SO4	**260**	10	"	20	"	"	"	"	
Hexane Extractable Material (HEM)	**33**	5.0	"	1	CP07807	10/10/06	10/10/06	EPA 1664	
pH	**8.58**	0.001	pH Units	"	CP07805	10/10/06	10/10/06	EPA 150.1	
Orthophosphate as PO4	ND	0.15	mg/L	"	CP07829	10/10/06	10/10/06	EPA 365.2	
Total Dissolved Solids	**1800**	10	"	"	CP07817	10/10/06	10/11/06	EPA 160.1	
Total Suspended Solids	**34**	5.0	"	"	CP07816	10/10/06	10/11/06	EPA 160.2	
West Side Tank (CPJ0336-02) Water Sampled: 10/09/06 16:40 Received: 10/09/06 17:35									
Specific Conductance (EC)	**2200**	1.0	µmhos/cm	1	CP07821	10/10/06	10/10/06	EPA 120.1	
Fluoride	**2.0**	1.0	mg/L	10	CP07801	10/10/06	10/10/06	EPA 300.0	
Chloride	**12**	5.0	"	"	"	"	"	"	
Nitrite as NO2	**570**	50	"	100	"	"	"	"	
Bromide	**0.38**	0.10	"	1	"	"	"	"	
Nitrate as NO3	**1.9**	0.50	"	"	"	"	"	"	
Sulfate as SO4	**210**	5.0	"	10	"	"	"	"	
Hexane Extractable Material (HEM)	**73**	7.6	"	1	CP07807	10/10/06	10/10/06	EPA 1664	
pH	**8.56**	0.001	pH Units	"	CP07805	10/10/06	10/10/06	EPA 150.1	
Orthophosphate as PO4	ND	0.15	mg/L	"	CP07829	10/10/06	10/10/06	EPA 365.2	
Total Dissolved Solids	**1600**	10	"	"	CP07817	10/10/06	10/11/06	EPA 160.1	
Total Suspended Solids	**34**	5.0	"	"	CP07816	10/10/06	10/11/06	EPA 160.2	

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01/09/07 09:13

ACTI 18414 So. Santa Fe Avenue Rancho Dominguez, CA 90221	Project: Alecs Project Number: [none] Project Manager: Robert Puga	**CLS Work Order #: CPJ0336** COC #: 76759

Metals by EPA 200 Series Methods

Analyte	Result	Reporting Limit	Units	Dilution	Batch	Prepared	Analyzed	Method	Notes
East Side Tank (CPJ0336-01) Water	**Sampled: 10/09/06 16:35**	**Received: 10/09/06 17:35**							
Aluminum	**110**	50	µg/L	1	CP07833	10/10/06	10/11/06	EPA 200.7	
Antimony	ND	50	"	"	"	"	"	"	
Arsenic	ND	100	"	"	"	"	"	"	
Barium	**35**	20	"	"	"	"	"	"	
Beryllium	ND	5.0	"	"	"	"	"	"	
Cadmium	ND	10	"	"	"	"	"	"	
Calcium	**45000**	1000	"	"	"	"	"	"	
Chromium	**11**	10	"	"	"	"	"	"	
Cobalt	ND	20	"	"	"	"	"	"	
Copper	ND	10	"	"	"	"	"	"	
Iron	**100**	100	"	"	"	"	"	"	
Lead	ND	50	"	"	"	"	"	"	
Magnesium	**3100**	1000	"	"	"	"	"	"	
Manganese	ND	20	"	"	"	"	"	"	
Molybdenum	**300**	20	"	"	"	"	"	"	
Nickel	ND	20	"	"	"	"	"	"	
Potassium	**2400**	1000	"	"	"	"	"	"	
Selenium	ND	100	"	"	"	"	"	"	
Silver	ND	10	"	"	"	"	"	"	
Sodium	**510000**	1000	"	"	"	"	"	"	
Strontium	**130**	20	"	"	"	"	"	"	
Thallium	ND	200	"	"	"	"	"	"	
Vanadium	ND	20	"	"	"	"	"	"	
Zinc	**75**	20	"	"	"	"	"	"	
Boron	**250**	50	"	"	"	"	"	"	
Tin	ND	100	"	"	"	"	"	"	
Titanium	ND	50	"	"	"	"	"	"	

CALIFORNIA LABORATORY SERVICES

01/09/07 09:13

ACTI
18414 So. Santa Fe Avenue
Rancho Dominguez, CA 90221

Project: Alecs
Project Number: [none]
Project Manager: Robert Puga

CLS Work Order #: CPJ0336
COC #: 76759

Conventional Chemistry Parameters by APHA/EPA Methods

Analyte	Result	Reporting Limit	Units	Dilution	Batch	Prepared	Analyzed	Method	Notes
East Side Tank (CPJ0336-01) Water Sampled: 10/09/06 16:35 Received: 10/09/06 17:35									
Specific Conductance (EC)	**2300**	1.0	µmhos/cm	1	CP07821	10/10/06	10/10/06	EPA 120.1	
Fluoride	**2.5**	2.0	mg/L	20	CP07801	10/10/06	10/10/06	EPA 300.0	
Chloride	**17**	10	"	"	"	"	"	"	
Nitrite as NO2	**500**	50	"	100	"	"	"	"	
Bromide	**0.59**	0.10	"	1	"	"	"	"	
Nitrate as NO3	**1.5**	0.50	"	"	"	"	"	"	
Sulfate as SO4	**260**	10	"	20	"	"	"	"	
Hexane Extractable Material (HEM)	**33**	5.0	"	1	CP07807	10/10/06	10/10/06	EPA 1664	
pH	**8.58**	0.001	pH Units	"	CP07805	10/10/06	10/10/06	EPA 150.1	
Orthophosphate as PO4	ND	0.15	mg/L	"	CP07829	10/10/06	10/10/06	EPA 365.2	
Total Dissolved Solids	**1800**	10	"	"	CP07817	10/10/06	10/11/06	EPA 160.1	
Total Suspended Solids	**34**	5.0	"	"	CP07816	10/10/06	10/11/06	EPA 160.2	
West Side Tank (CPJ0336-02) Water Sampled: 10/09/06 16:40 Received: 10/09/06 17:35									
Specific Conductance (EC)	**2200**	1.0	µmhos/cm	1	CP07821	10/10/06	10/10/06	EPA 120.1	
Fluoride	**2.0**	1.0	mg/L	10	CP07801	10/10/06	10/10/06	EPA 300.0	
Chloride	**12**	5.0	"	"	"	"	"	"	
Nitrite as NO2	**570**	50	"	100	"	"	"	"	
Bromide	**0.38**	0.10	"	1	"	"	"	"	
Nitrate as NO3	**1.9**	0.50	"	"	"	"	"	"	
Sulfate as SO4	**210**	5.0	"	10	"	"	"	"	
Hexane Extractable Material (HEM)	**73**	7.6	"	1	CP07807	10/10/06	10/10/06	EPA 1664	
pH	**8.56**	0.001	pH Units	"	CP07805	10/10/06	10/10/06	EPA 150.1	
Orthophosphate as PO4	ND	0.15	mg/L	"	CP07829	10/10/06	10/10/06	EPA 365.2	
Total Dissolved Solids	**1600**	10	"	"	CP07817	10/10/06	10/11/06	EPA 160.1	
Total Suspended Solids	**34**	5.0	"	"	CP07816	10/10/06	10/11/06	EPA 160.2	

CALIFORNIA LABORATORY SERVICES

3249 Fitzgerald Road Rancho Cordova, CA 95742

January 09, 2007

CLS Work Order #: CPJ0336
COC #: 76759

Robert Puga
ACTI
18414 So. Santa Fe Avenue
Rancho Dominguez, CA 90221

Project Name: Alecs

Enclosed are the results of analyses for samples received by the laboratory on 10/09/06 17:35. Samples were analyzed pursuant to client request utilizing EPA or other ELAP approved methodologies. I certify that the results are in compliance both technically and for completeness.

Analytical results are attached to this letter. Please call if we can provide additional assistance.

Sincerely,

James Liang, Ph.D.
Laboratory Director

CA DOHS ELAP Accreditation/Registration number 1233

CALIFORNIA LABORATORY SERVICES

01/09/07 09:13

ACTI 18414 So. Santa Fe Avenue Rancho Dominguez, CA 90221	Project: Alecs Project Number: [none] Project Manager: Robert Puga	**CLS Work Order #: CPJ0336** COC #: 76759

Conventional Chemistry Parameters by APHA/EPA Methods - Quality Control

Analyte	Result	Reporting Limit	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Notes
Batch CP07801 - General Prep										
Matrix Spike Dup (CP07801-MSD1)	**Source: CPJ0343-01**			Prepared & Analyzed: 10/10/06						
Fluoride	2.34	0.10	mg/L	2.00	0.19	108	75-125	4.37	25	
Chloride	9.24	0.50	"	2.00	7.3	97.0	75-125	2.08	25	
Nitrite as NO2	2.02	0.50	"	2.00	ND	101	75-125	4.04	25	
Bromide	2.11	0.10	"	2.00	ND	106	75-125	3.37	25	
Nitrate as NO3	2.14	0.50	"	2.00	ND	107	75-125	3.33	25	
Sulfate as SO4	17.2	0.50	"	5.00	12	104	75-125	2.35	25	
Batch CP07807 - Solvent Extract										
Blank (CP07807-BLK1)				Prepared & Analyzed: 10/10/06						
Hexane Extractable Material (HEM)	ND	5.0	mg/L							
LCS (CP07807-BS1)				Prepared & Analyzed: 10/10/06						
Hexane Extractable Material (HEM)	41.1	5.0	mg/L	40.0		103	80-120		20	
LCS Dup (CP07807-BSD1)				Prepared & Analyzed: 10/10/06						
Hexane Extractable Material (HEM)	41.3	5.0	mg/L	40.0		103	80-120	0.485	20	
Batch CP07816 - General Preparation										
Blank (CP07816-BLK1)				Prepared: 10/10/06 Analyzed: 10/11/06						
Total Suspended Solids	ND	5.0	mg/L							
Batch CP07817 - General Preparation										
Blank (CP07817-BLK1)				Prepared: 10/10/06 Analyzed: 10/11/06						
Total Dissolved Solids	ND	10	mg/L							

ACTI
18414 So. Santa Fe Avenue
Rancho Dominguez, CA 90221

Project: Alecs
Project Number: [none]
Project Manager: Robert Puga

CLS Work Order #: CPJ0336
COC #: 76759

Conventional Chemistry Parameters by APHA/EPA Methods - Quality Control

Analyte	Result	Reporting Limit	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Notes
Batch CP07821 - General Preparation										
Blank (CP07821-BLK1)				Prepared & Analyzed: 10/10/06						
Specific Conductance (EC)	ND	1.0	µmhos/cm							
Batch CP07829 - General Preparation										
Blank (CP07829-BLK1)				Prepared & Analyzed: 10/10/06						
Orthophosphate as PO4	ND	0.15	mg/L							
LCS (CP07829-BS1)				Prepared & Analyzed: 10/10/06						
Orthophosphate as PO4	0.947	0.15	mg/L	0.918		103	80-120		20	
LCS Dup (CP07829-BSD1)				Prepared & Analyzed: 10/10/06						
Orthophosphate as PO4	0.907	0.15	mg/L	0.918		98.8	80-120	4.31	20	
Matrix Spike (CP07829-MS1)	**Source: CPJ0342-01**			Prepared & Analyzed: 10/10/06						
Orthophosphate as PO4	0.947	0.15	mg/L	0.918	0.013	102	75-125		25	
Matrix Spike Dup (CP07829-MSD1)	**Source: CPJ0342-01**			Prepared & Analyzed: 10/10/06						
Orthophosphate as PO4	0.943	0.15	mg/L	0.918	0.013	101	75-125	0.423	25	

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ACTI 18414 So. Santa Fe Avenue Rancho Dominguez, CA 90221	Project: Alecs Project Number: [none] Project Manager: Robert Puga	**CLS Work Order #: CPJ0336** COC #: 76759

Metals by EPA 200 Series Methods - Quality Control

Analyte	Result	Reporting Limit	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Notes
Batch CP07833 - EPA 3010A										
Blank (CP07833-BLK1)				Prepared & Analyzed: 10/10/06						
Aluminum	ND	50	µg/L							
Antimony	ND	50	"							
Arsenic	ND	100	"							
Barium	ND	20	"							
Beryllium	ND	5.0	"							
Cadmium	ND	10	"							
Calcium	ND	1000	"							
Chromium	ND	10	"							
Cobalt	ND	20	"							
Copper	ND	10	"							
Iron	ND	100	"							
Lead	ND	50	"							
Magnesium	ND	1000	"							
Manganese	ND	20	"							
Molybdenum	ND	20	"							
Nickel	ND	20	"							
Potassium	ND	1000	"							
Selenium	ND	100	"							
Silver	ND	10	"							
Sodium	ND	1000	"							
Strontium	ND	20	"							
Thallium	ND	200	"							
Vanadium	ND	20	"							
Zinc	ND	20	"							
Boron	ND	50	"							
Tin	ND	100	"							
Titanium	ND	50	"							

CALIFORNIA LABORATORY SERVICES

01/09/07 09:13

ACTI 18414 So. Santa Fe Avenue Rancho Dominguez, CA 90221	Project: Alecs Project Number: [none] Project Manager: Robert Puga	**CLS Work Order #: CPJ0336** COC #: 76759

Metals by EPA 200 Series Methods - Quality Control

Analyte	Result	Reporting Limit	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Notes
Batch CP07833 - EPA 3010A										
LCS (CP07833-BS1)				Prepared & Analyzed: 10/10/06						
Aluminum	1720	50	µg/L	2000		86.0	80-120		20	
Antimony	418	50	"	500		83.6	80-120		20	
Arsenic	2260	100	"	2000		113	80-120		20	
Barium	1840	20	"	2000		92.0	80-120		20	
Beryllium	44.3	5.0	"	50.0		88.6	80-120		20	
Cadmium	43.9	10	"	50.0		87.8	80-120		20	
Calcium	8690	1000	"	10000		86.9	80-120		20	
Chromium	190	10	"	200		95.0	80-120		20	
Cobalt	455	20	"	500		91.0	80-120		20	
Copper	235	10	"	250		94.0	80-120		20	
Iron	890	100	"	1000		89.0	80-120		20	
Lead	463	50	"	500		92.6	80-120		20	
Magnesium	8970	1000	"	10000		89.7	80-120		20	
Manganese	452	20	"	500		90.4	80-120		20	
Molybdenum	455	20	"	500		91.0	80-120		20	
Nickel	440	20	"	500		88.0	80-120		20	
Potassium	9120	1000	"	10000		91.2	80-120		20	
Selenium	1790	100	"	2000		89.5	80-120		20	
Silver	46.5	10	"	50.0		93.0	80-120		20	
Sodium	9120	1000	"	10000		91.2	80-120		20	
Strontium	464	20	"	500		92.8	80-120		20	
Thallium	1720	200	"	2000		86.0	80-120		20	
Vanadium	457	20	"	500		91.4	80-120		20	
Zinc	473	20	"	500		94.6	80-120		20	
Boron	2240	50	"	2500		89.6	80-120		20	
Tin	1970	100	"	2000		98.5	80-120		20	
Titanium	1820	50	"	2000		91.0	80-120		20	

CALIFORNIA LABORATORY SERVICES

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ACTI 18414 So. Santa Fe Avenue Rancho Dominguez, CA 90221	Project: Alecs Project Number: [none] Project Manager: Robert Puga	**CLS Work Order #: CPJ0336** COC #: 76759

Metals by EPA 200 Series Methods - Quality Control

Analyte	Result	Reporting Limit	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Notes
Batch CP07833 - EPA 3010A										
LCS Dup (CP07833-BSD1)				Prepared & Analyzed: 10/10/06						
Aluminum	1710	50	µg/L	2000		85.5	80-120	0.583	20	
Antimony	431	50	"	500		86.2	80-120	3.06	20	
Arsenic	2250	100	"	2000		112	80-120	0.443	20	
Barium	1830	20	"	2000		91.5	80-120	0.545	20	
Beryllium	43.3	5.0	"	50.0		86.6	80-120	2.28	20	
Cadmium	41.0	10	"	50.0		82.0	80-120	6.83	20	
Calcium	8580	1000	"	10000		85.8	80-120	1.27	20	
Chromium	189	10	"	200		94.5	80-120	0.528	20	
Cobalt	451	20	"	500		90.2	80-120	0.883	20	
Copper	233	10	"	250		93.2	80-120	0.855	20	
Iron	883	100	"	1000		88.3	80-120	0.790	20	
Lead	458	50	"	500		91.6	80-120	1.09	20	
Magnesium	8900	1000	"	10000		89.0	80-120	0.783	20	
Manganese	447	20	"	500		89.4	80-120	1.11	20	
Molybdenum	457	20	"	500		91.4	80-120	0.439	20	
Nickel	440	20	"	500		88.0	80-120	0.00	20	
Potassium	9110	1000	"	10000		91.1	80-120	0.110	20	
Selenium	1780	100	"	2000		89.0	80-120	0.560	20	
Silver	46.0	10	"	50.0		92.0	80-120	1.08	20	
Sodium	9030	1000	"	10000		90.3	80-120	0.992	20	
Strontium	459	20	"	500		91.8	80-120	1.08	20	
Thallium	1750	200	"	2000		87.5	80-120	1.73	20	
Vanadium	452	20	"	500		90.4	80-120	1.10	20	
Zinc	466	20	"	500		93.2	80-120	1.49	20	
Boron	2220	50	"	2500		88.8	80-120	0.897	20	
Tin	1940	100	"	2000		97.0	80-120	1.53	20	
Titanium	1810	50	"	2000		90.5	80-120	0.551	20	

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ACTI 18414 So. Santa Fe Avenue Rancho Dominguez, CA 90221	Project: Alecs Project Number: [none] Project Manager: Robert Puga	**CLS Work Order #: CPJ0336** COC #: 76759

Metals by EPA 200 Series Methods - Quality Control

Analyte	Result	Reporting Limit	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Notes
Batch CP07833 - EPA 3010A										
Matrix Spike (CP07833-MS1)		**Source: CPJ0343-01**		Prepared & Analyzed: 10/10/06						
Aluminum	1660	50	µg/L	2000	ND	83.0	75-125		25	
Antimony	433	50	"	500	ND	86.6	75-125		25	
Arsenic	2100	100	"	2000	ND	105	75-125		25	
Barium	1880	20	"	2000	130	87.5	75-125		25	
Beryllium	42.0	5.0	"	50.0	ND	84.0	75-125		25	
Cadmium	35.8	10	"	50.0	ND	71.6	75-125		25	QM-7
Calcium	14800	1000	"	10000	7600	72.0	75-125		25	QM-7
Chromium	176	10	"	200	ND	88.0	75-125		25	
Cobalt	424	20	"	500	ND	84.8	75-125		25	
Copper	225	10	"	250	ND	90.0	75-125		25	
Iron	2450	100	"	1000	1800	65.0	75-125		25	QM-7
Lead	439	50	"	500	ND	87.8	75-125		25	
Magnesium	12200	1000	"	10000	3700	85.0	75-125		25	
Manganese	889	20	"	500	510	75.8	75-125		25	
Molybdenum	433	20	"	500	ND	86.6	75-125		25	
Nickel	410	20	"	500	ND	82.0	75-125		25	
Potassium	14100	1000	"	10000	5400	87.0	75-125		25	
Selenium	1680	100	"	2000	ND	84.0	75-125		25	
Silver	26.2	10	"	50.0	3.0	46.4	75-125		25	QM-7
Sodium	25800	1000	"	10000	17000	88.0	75-125		25	
Strontium	546	20	"	500	110	87.2	75-125		25	
Thallium	1700	200	"	2000	ND	85.0	75-125		25	
Vanadium	427	20	"	500	ND	85.4	75-125		25	
Zinc	494	20	"	500	60	86.8	75-125		25	
Boron	2140	50	"	2500	32	84.3	75-125		25	
Tin	1860	100	"	2000	ND	93.0	75-125		25	
Titanium	1730	50	"	2000	ND	86.5	75-125		25	

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ACTI 18414 So. Santa Fe Avenue Rancho Dominguez, CA 90221	Project: Alecs Project Number: [none] Project Manager: Robert Puga	**CLS Work Order #: CPJ0336** COC #: 76759

Metals by EPA 200 Series Methods - Quality Control

Analyte	Result	Reporting Limit	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Notes
Batch CP07833 - EPA 3010A										
Matrix Spike Dup (CP07833-MSD1)		**Source: CPJ0343-01**		Prepared & Analyzed: 10/10/06						
Aluminum	1640	50	µg/L	2000	ND	82.0	75-125	1.21	25	
Antimony	430	50	"	500	ND	86.0	75-125	0.695	25	
Arsenic	2080	100	"	2000	ND	104	75-125	0.957	25	
Barium	1870	20	"	2000	130	87.0	75-125	0.533	25	
Beryllium	41.9	5.0	"	50.0	ND	83.8	75-125	0.238	25	
Cadmium	38.0	10	"	50.0	ND	76.0	75-125	5.96	25	
Calcium	14800	1000	"	10000	7600	72.0	75-125	0.00	25	QM-7
Chromium	173	10	"	200	ND	86.5	75-125	1.72	25	
Cobalt	422	20	"	500	ND	84.4	75-125	0.473	25	
Copper	219	10	"	250	ND	87.6	75-125	2.70	25	
Iron	2440	100	"	1000	1800	64.0	75-125	0.409	25	QM-7
Lead	424	50	"	500	ND	84.8	75-125	3.48	25	
Magnesium	12100	1000	"	10000	3700	84.0	75-125	0.823	25	
Manganese	885	20	"	500	510	75.0	75-125	0.451	25	
Molybdenum	429	20	"	500	ND	85.8	75-125	0.928	25	
Nickel	409	20	"	500	ND	81.8	75-125	0.244	25	
Potassium	13900	1000	"	10000	5400	85.0	75-125	1.43	25	
Selenium	1680	100	"	2000	ND	84.0	75-125	0.00	25	
Silver	31.2	10	"	50.0	3.0	56.4	75-125	17.4	25	QM-7
Sodium	25600	1000	"	10000	17000	86.0	75-125	0.778	25	
Strontium	544	20	"	500	110	86.8	75-125	0.367	25	
Thallium	1710	200	"	2000	ND	85.5	75-125	0.587	25	
Vanadium	424	20	"	500	ND	84.8	75-125	0.705	25	
Zinc	495	20	"	500	60	87.0	75-125	0.202	25	
Boron	2130	50	"	2500	32	83.9	75-125	0.468	25	
Tin	1860	100	"	2000	ND	93.0	75-125	0.00	25	
Titanium	1720	50	"	2000	ND	86.0	75-125	0.580	25	

ACTI 18414 So. Santa Fe Avenue Rancho Dominguez, CA 90221	Project: Alecs Project Number: [none] Project Manager: Robert Puga	**CLS Work Order #: CPJ0336** COC #: 76759

Notes and Definitions

QM-7	The spike recovery was outside acceptance limits for the MS and/or MSD. The batch was accepted based on acceptable LCS/LCSD recovery.
DET	Analyte DETECTED
ND	Analyte NOT DETECTED at or above the reporting limit
NR	Not Reported
dry	Sample results reported on a dry weight basis
RPD	Relative Percent Difference